# RADIOLOGICAL DEFENSE

## Vol. IV

The Armed Forces Special Weapons Project

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## Vol. IV

A

Manual

Prepared by the

Armed Forces Special Weapons Project

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# Radiological Defense, Vol. IV

# RADIAC

## An Introduction to Radiological Instruments for Military Use

by

D. C. Campbell, LCDR, USN

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## FOREWORD

This volume is the fourth of a series of Radiological Defense Manuals issued by the Armed Forces Special Weapons Project for training purposes in the Department of Defense. The objective of Volume IV is to present certain phases of the radiological instrumentation program in such form as to assist defense personnel in preparing themselves for the complex detection problem which must be faced during atomic warfare.

Aspects of the program are presented as seen today. It is anticipated that research and development now under way will make many of the instruments herein described obsolete within a period of 18 months.

The volume combines with the description of specific instruments a basic consideration of the mechanism of radiation detection and an indication of possible operational use, so that field personnel may be given a comprehensive picture of the role to be played by radiological instrumentation during atomic warfare.

K. D. Nichols

K. D. NICHOLS
*Major General, USA*
*Chief, Armed Forces Special Weapons Project*

JANUARY 1950

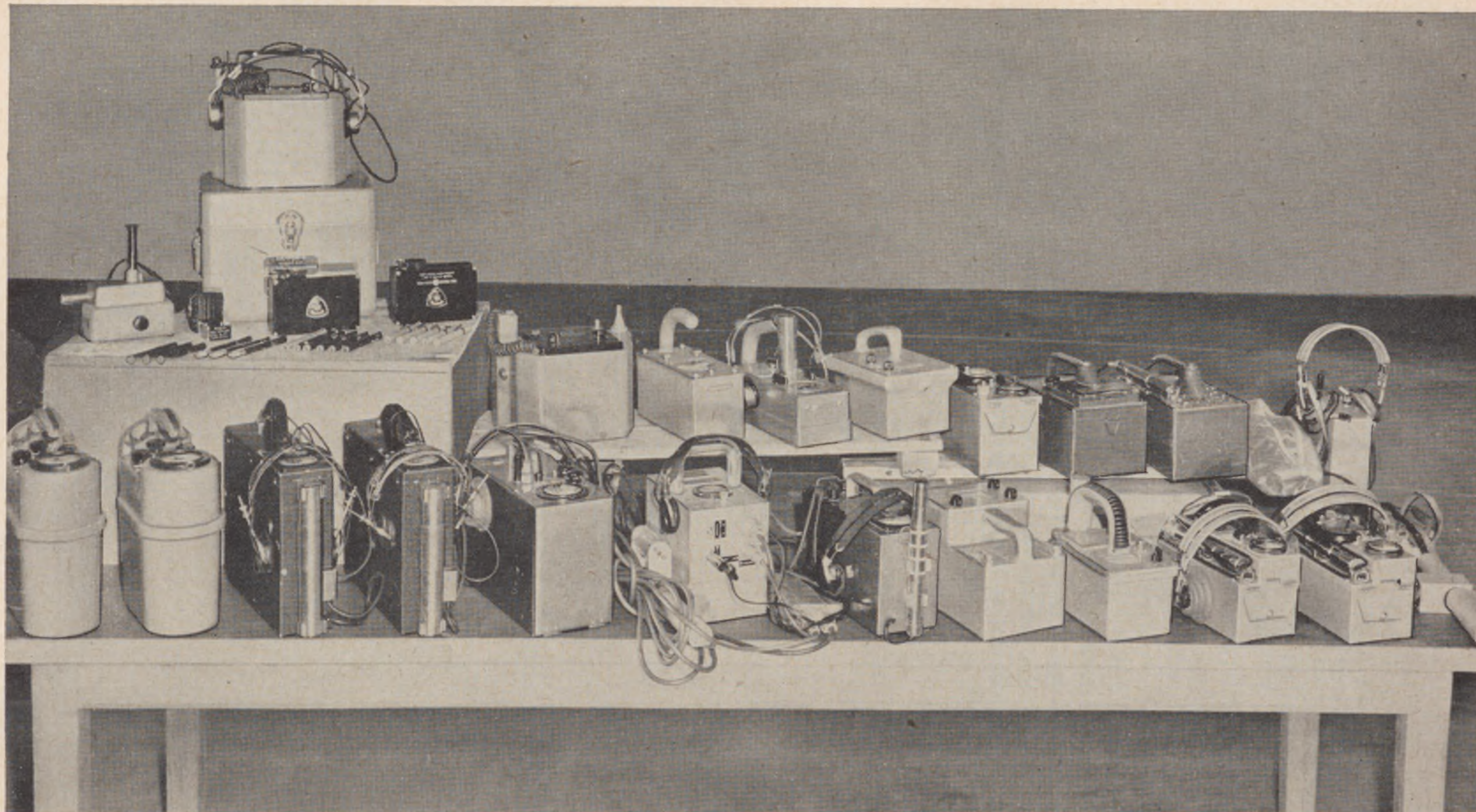


*Figure 1. Work is under way to develop satisfactory radiac instruments.*

Shown are representative models of both commercial and military portable instruments of types which are of immediate interest to the Defense Establishment.

# RADIATION INSTRUMENTS FOR MILITARY USE

## Chapter 1

## INTRODUCTION

The development of the atomic bomb and the possible development of radiological warfare agents require that future military plans contain a certain emphasis on radiological defense. Instruments are a basic requirement in any such defense plan, since nature has not equipped man with senses capable of responding to nuclear radiations. Irreparable damage may be produced in high intensity fields which cannot be recognized without the use of suitable instruments.

Since the first atomic bomb explosion, increasing emphasis and thought have been placed upon the development of instruments suitable for military use. The instrumentation requirements are in many respects similar to those which have been encountered in X-ray radiographic and therapeutic use, radium radiographic and therapeutic use, isotope research and therapeutic use, cosmic ray research, and investigations with high energy accelerators. Military instruments in general require, in addition, an ability to withstand rough usage under extreme weather, temperature, and geographic conditions. They should also be made as simple and foolproof as is possible within the limits of their detecting requirement.

The field of radiological instrumentation, as it applies to the defense establishment, has been assigned the name "RADIAC". This new word for the military vocabulary has been taken from the initial letters of—RAdiation, Detection, Indication, And Computation.

# Chapter 2

# RADIATION IN GENERAL

## 2.01 Introduction

Radiation, in the sense in which we are concerned, means nuclear emissions and is not concerned with the radiations which are manifest as radio waves, heat, and light (1) (2).* It is possible to separate these nuclear emissions into electrically charged and electrically neutral categories.

The electrically charged radiation consists of particles in motion such as:

- beta ($\beta$) particles (electrons—$e^-$)
- alpha ($\alpha$) particles (helium nuclei—$He^{++}$)
- protons ($p$) (hydrogen nuclei) (no military importance)
- positron (positive electron) (no military importance)

The electrically neutral radiation consists of:

- neutron ($n$)
- gamma rays ($\gamma$)
- X-rays (not considered as a nuclear radiation)

Except in a few unique applications, military consideration is given to the measurement of the charged alpha and beta particles and to the electrically neutral gamma rays. Of these radiations, the greatest emphasis is placed on measurement of gamma rays. Table I gives some rough comparisons of the characteristics of alpha and beta particles and gamma rays.

The measurement of neutrons will become important in conjunction with the operation of nuclear reactors for power production or the propulsion of ships or aircraft. Detection of neutrons involves some specialized applications of the detecting principles which will be discussed. However, a detailed description of neutron detection will be omitted, since neutrons at present are of limited interest to the Defense Establishment.

It should be noted that there are certain elements which give off pure alpha and pure beta radiations. Gamma radiations are produced only as an after-effect of either an alpha or a beta emission. With very minor exceptions, there is no such thing as a pure gamma emitter, although in some cases the alpha or beta emissions may be so weak as to be virtually indetectable.

TABLE I.—*Characteristics of nuclear radiation*

| Radiation | Nature | Energy | Ionizing power in air | Penetration | Range in standard air |
|---|---|---|---|---|---|
| Alpha Particle | Heavy positively charged particle. Helium nucleus $He^{++}$. Velocity 0 to $2 \times 10^9$ cm/sec. | High 4–9 Mev** | High 40,000–250,000 ion pairs; 20,000–80,000 ion pairs per centimeter | 5.5 Mev—$4.06 \times 10^{-3}$ cm in Alumium | 7 Mev—6.0 cm<br>5 Mev—3.48 cm<br>2.0 Mev—1.0 cm<br>0.2 Mev—0.17 cm |
| Beta Particle | Light negatively charged particle. Electron $e^-$. Velocities up to 99.7% that of light | Up to Medium High, 0–3 Mev | Medium 30–300 ion pairs per centimeter | 0.15 Mev—1.0 mm; 2 Mev—3.5 mm in Aluminum | 0.2 Mev—37 cm<br>2 Mev—840 cm |
| Gamma Ray | Electromagnetic radiation. Wave length from $5 \times 10^{-10}$ to $4 \times 10^{-8}$ cm. Uncharged | Low to Medium High, 0.03 – 2.6 Mev | Low 0+ | Lower intensity expotentially along its path | Thickness to reduce intensity of 1 Mev to one-half:<br>Air—350 feet<br>Lead—0.9 cm |

**Mev=Million electron volts=amount of work done when one electron is accelerated by a potential difference of one million volts.

*Numbers in parentheses indicate references on page 83 of this manual.

## 2.02 Electrically Neutral Radiation

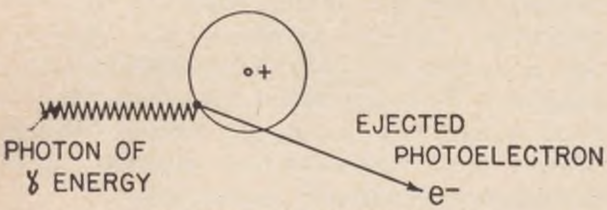
The fact that gamma (or X-rays) are uncharged means that it is not possible to detect them directly with present types of measuring equipment. Fortunately these radiations in their passage through matter produce secondary processes which allow measurement.

In order to understand the methods of measurement of gamma rays, it is necessary to consider the manner in which neutral radiation is absorbed. It can be shown that absorption, or attenuation, takes place by several processes, the most important being the following:

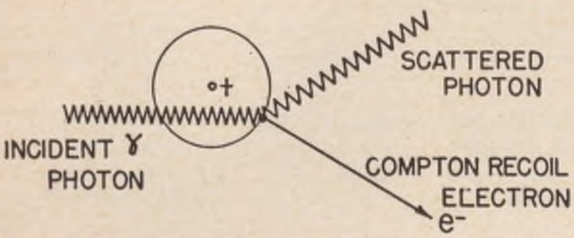
A. Photoelectric Effect

As shown in figure 2a, an atom irradiated with gamma rays absorbs the radiation by ejecting an electron. This type of absorption is dependent on the absorbing medium, but as a rough rule, is only important with gamma rays having energies below 0.1 Mev.

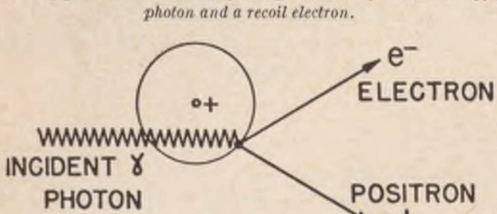
B. Compton Effect




*a. Photoelectric absorption of a gamma ray photon.*




*b. Gamma ray photon absorbed through the production of a lower energy gamma photon and a recoil electron.*




*c. Gamma photon being absorbed with the production of an electron pair. This only occurs in the vicinity of the nucleus.*

*Figure 2. Gamma ray absorption.*

Three methods of gamma ray absorption are shown by means of schematic diagrams. It will be noted that a negative electron ($e^-$) is produced by each method.

In some cases, photons of gamma radiation behave like billiard balls and produce the effect shown in figure 2b. Energy is absorbed from the incident photon to eject an electron. The scattered photon has, as a result, lower energy than the incident photon. This effect is important in the range of energies up to roughly 1 to 10 Mev.

C. Pair Production

With high energies above 1 Mev, pair production becomes possible, and becomes predominant in the region 5–12 Mev and above, being more important in absorbers of high atomic weight. Diagrammatically, this is shown in figure 2c where a high energy gamma photon is absorbed by producing a pair of electrons. As shown all three methods of absorption result in the production of high energy electrons which are electrically charged particles of the same general type as beta particles.

It should be reemphasized that only if uncharged radiations are instrumental in producing charged radiations through some secondary process can they be detected or measured by the various means which will be discussed.

## 2.03 Electrically Charged Radiation

Several possibilities present themselves for the measurement of electrically charged particles. Methods employing gas ionization prove to be the most convenient and practical. When a charged particle enters a gas it may act on a neutral gas atom or molecule with sufficient energy to remove one or more electrons. This process is called *ionization* and results in a single neutral atom or molecule being split into two (or more) electrically charged particles—the negative electron(s) and the positively charged remaining portion of the atom or molecule. The removal of a single electron produces what is called an *ion pair*. The energy required to produce ion pairs depends upon the particular gas involved. In the case of air, which is a mixture of gases, the average loss of energy by the electrically charged particle is about 32.5 electron volts for each ion pair produced. This does not mean that 32.5 electron volts go into the formation of the ion pair. Actually, only about half of this value is used specifically to strip off the electron in an ionizing collision. The remainder of the 32.5 electron volts is given up in the excitation of gas molecules in inelastic collisions which do not produce ions or in providing kinetic energy to the members of

and ion pair if ionization is produced. We will discuss later the excitation phenomenon in connection with certain crystals, but for the moment ionization is of the greatest interest.

In the process of ionization, particles having greater electrical charge will produce greater ionization. Also, the more massive particles moving with lower velocities will present longer periods of time in which forces can act and, as a result, will be more effective in producing ionization than less massive particles. As an example, the transit in air of the negatively charged beta particle will produce between 30 and 300 ion pairs per centimeter of path length with the higher ionization occurring for lower beta particle energies. The heavier, doubly charged positive alpha particle will produce anywhere from 20,000 to 80,000 ion pairs per centimeter of travel.

The ion pairs produced in a gas by the transit of an electrically charged particle will recombine to form neutral molecules. In the case of air at atmospheric pressure the life of an ion pair is believed to be in the order of five minutes. If, prior to recombination, the particles are subjected to an electric field, they will move under the influence of the field, the positive ions toward the negatively charged cathode, and the negative ions toward the positively charged anode. A gas filled chamber containing electrons which have sufficient strength to collect all of the initially formed charge is called an *ionization chamber*. The electric field strength required for charge collection in chambers generally is between 15 and 120 volts per centimeter and usually is not critical. This voltage corresponds to the field necessary to collect the ions prior to appreciable recombination and is not high enough to produce additional ion pairs as the ions travel to the collecting electrodes.

## Chapter 3

# IONIZATION CHAMBER

### 3.01 Introduction

With appropriate forms of chambers all ionizing radiations can be detected (4). In the case of heavily ionizing radiations such as alpha particles (and in some cases electrons), separate ionizing events can be counted in a manner similar to that which will be described for Geiger-Mueller and proportional counters. Design characteristics of instruments are thoroughly entwined with operational usage and the type of radiation involved. In general, the chambers are built around three basic forms:

A. Two parallel electrode plates, one highly insulated and directly connected to the measuring part of the instrument.

B. Cylindrical electrode with a coaxial collecting rod.

C. Rectangular box with an internal collecting network (sometimes called a *Christmas tree*). In practice, form C is little more than an adaptation of the cylindrical condenser in B.

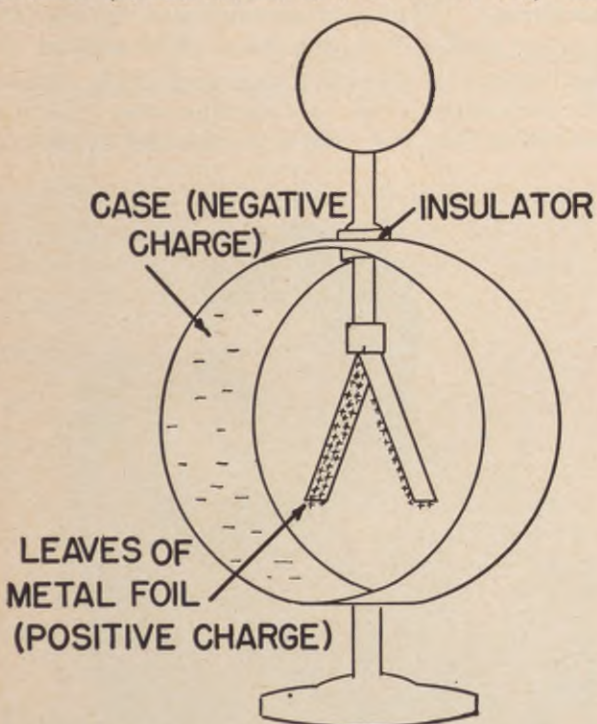



*Figure 3. Laboratory type electroscope.*

Separation of leaves is caused by the repulsive force between two like charges.

The anode and cathode previously mentioned, may take the form of electrodes in a simple electroscope in which the chamber (container) forms one electrode and the central wire and thin gold foil form the other electrode as shown in figure 3.

The electrostatic field produced by the positive charge on the central electrode and the negative charge on the case exerts a force on the charge on the gold leaves which causes the leaves to separate. Ions formed inside the chamber by radiation will neutralize the charge on the gold foil leaves, and the leaves will move together. Thus, within certain limits, it is possible to read radiation dose as a function of position of the sensitive element of an electroscope (3). An *electroscope* has no external voltage source, however, if the instrument used for the measurement of the electric charge collected in an ionization chamber utilizes a continuous external voltage for its operation it is called an *electrometer*.

### 3.02 Pocket Dosimeter

A useful military instrument is the *quartz fibre pocket dosimeter* which is a modified version of the *Lauritsen Electroscope* (1). A dosimeter is pictured in figure 4. This instrument, about the size of a fountain pen, utilizes a metallic coated quartz fibre some five microns (0.0002 inch) in diameter as the sensitive moving element in place of the thin gold foil in our previous example. The instrument incorporates a small compound microscope for viewing the fibre against a calibrated scale. Some type of light source must be available in order to see the scale and fibre. These dosimeters, having a full scale sensitivity 0.2 roentgen (r),* are in common use for measuring integrated gamma ray exposures. Work is under way to produce pocket dosimeters having full scale readings, perhaps as high as 200 roentgens. Pocket dosimeter reading and charging is shown in figures 5 and 6.

*See page 52 for an exact definition of a *roentgen*. (This is a unit of measurement of gamma or X-ray dosage rate or absorption.)

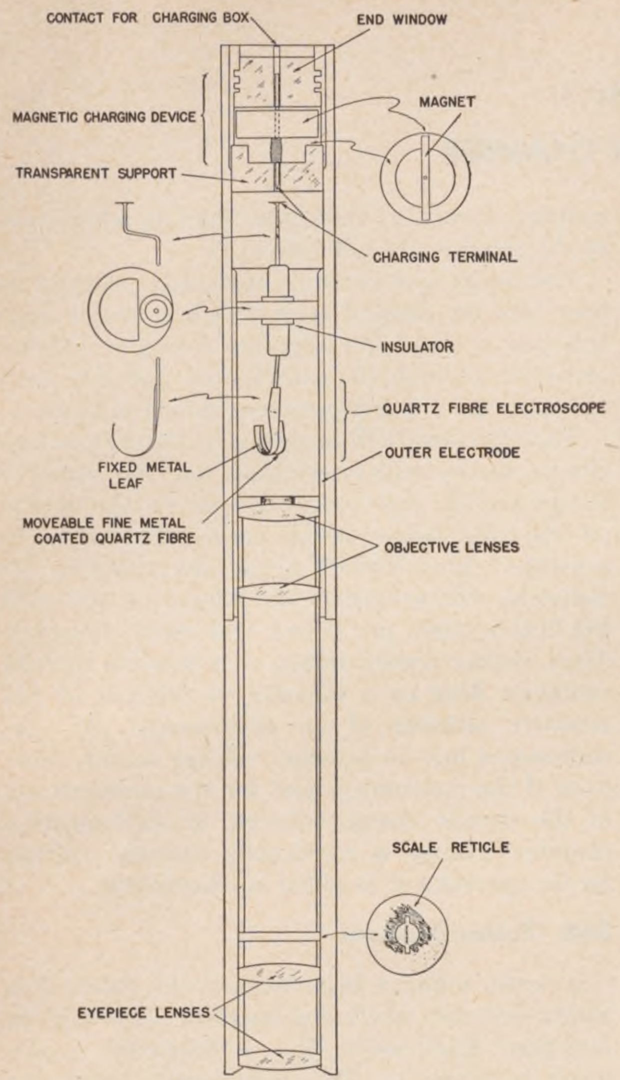



*Figure 4. Pocket dosimeter.*

Shown is the dosimeter with the magnetic charging device recently developed by Dr. F. R. Shonka of the Argonne National Laboratory. A magnet in the charger repels the dosimeter magnet and moves it into position so that the electroscope can be charged. Many dosimeters incorporate diaphragm charging terminals such as that shown with the pocket chamber in figure 8.

### 3.03 Drift Meter

A medium sized portable gamma measuring, alpha and beta indicating, survey instrument has been built with a quartz fibre system similar to that used in the pocket dosimeter. In some areas this instrument goes under the name *Landsverk Electroscope*. The unit has an enlarged chamber and is designed for portable but not pocket use. Since it is not a pocket device the charger is built in as a part of the instrument. Dosage rate is obtained by timing the rate of electroscope fibre movement. Timing is accomplished by the repetitive flashes of a neon lamp which appears to the viewer just above the microscope scale. Since the instrument keeps its calibration over extended periods of time, it is used as a secondary standard.

*Figure 5. Reading the pocket dosimeter.*

A light source must be available to see the scale and fibre. Here a reading is made using sky light for illumination.

*Figure 6. Charging a pocket dosimeter.*

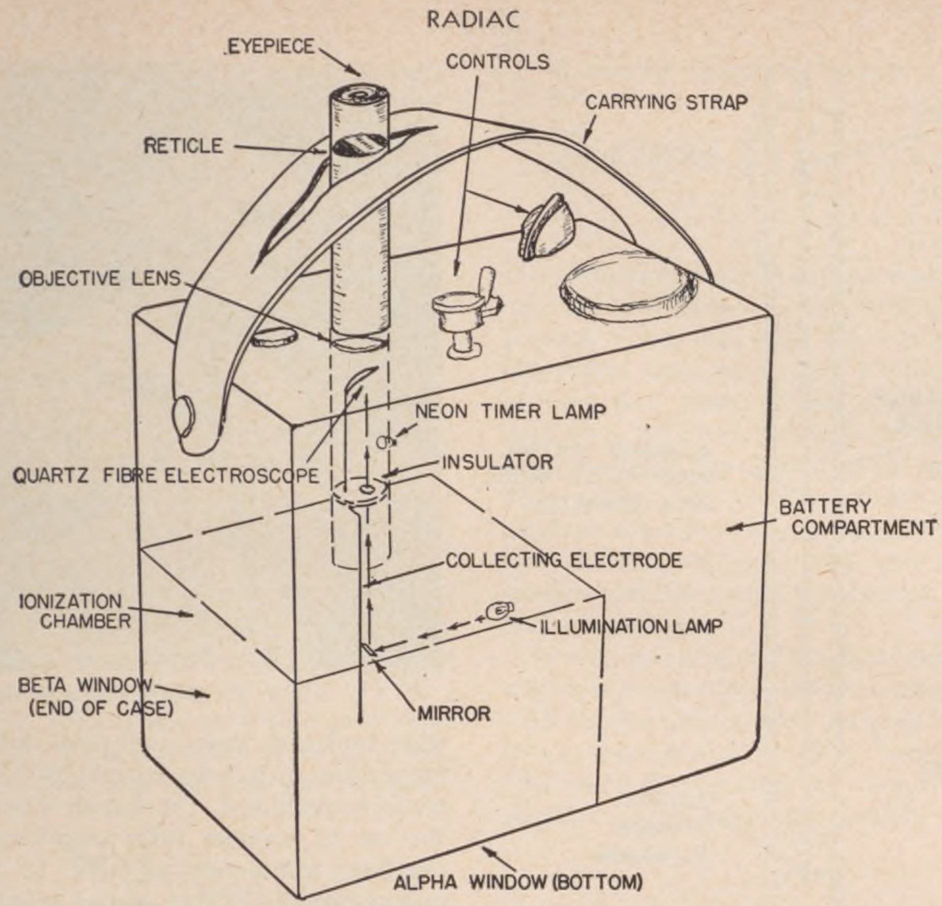



*Figure 7. Schematic drawing of quartz fibre survey instrument.*

Thin windows in the bottom and end of the chamber case make possible the detection of beta and alpha radiations.

The instrument can be made extremely rugged as a gamma reading instrument. The problems associated with thin windows necessary for alpha and beta admission to the chamber will be discussed later. Figure 7 shows a type of commercially available *drift meter*.

### 3.04 Pocket Chamber

The charge on the chamber electrodes can be measured, and any decrease in charge over a period of time can be calibrated to give a measure of the radiation dose which has produced the charge decrease. For a number of years *thimble chambers* have been built to record X-ray dosages up to 2500 roentgens for energies between 0.08 and 0.25 Mev.

The *pocket chamber*, figure 8, again about the size of a fountain pen, is an instrument utilizing this principle. Usually the instrument required to place the charge on the pocket chamber is used at some later time to read any decrease in charge. These instruments are more simply designed, and as a result, less costly than the pocket dosimeters ($5 as compared to $40). They have a use in military operations where it is desired for one reason or another to prevent the wearer from knowing the dose he has received. A great number of pocket chambers are in use which have a total sensitivity of 0.2 roentgen gamma exposure. Other pocket chambers are being constructed which have gamma sensitivities of 100 roentgens and there are considerations of chambers reading as high as 1000 roentgens. The wearing and reading of pocket chambers is shown in figures 9 and 10.

### 3.05 Electrometers

Metal coated quartz fibres mounted on a torsion fibre between electrodes are used as electrometers for ion detection. Several forms have been developed which have found some use in the laboratory measurement of alpha particles and low energy beta rays. The application of an external potential to the electrodes produces an instrument which is somewhat more sensitive than the elec-

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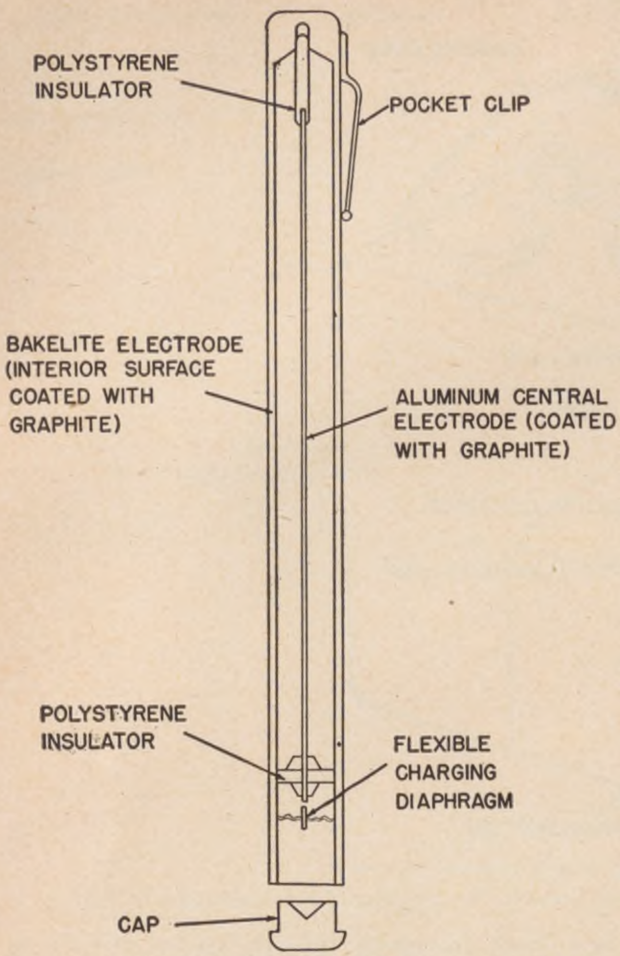



*Figure 8. Personnel pocket chamber.*

This is a non self-reading gamma dosage indicating device about the size of a fountain pen.

troscope. In most general use in this country are the *Wulf* and the *Lindemann* electrometers. However, aside from possible laboratory usage the quartz fibre electrometer has little military application.

If radiations are allowed to produce ions in the space between two electrodes, as shown in figure 13, and an electric field is induced to pull the ions from the region in which they were created the positive ions will move toward the cathode (central wire), and the electrons which are produced at the same time will move in the opposite direction toward the anode (chamber case). Current will therefore flow in the circuit until all ions are collected. This *ionization current* is very small. In the case of a one-litre chamber having air under standard conditions of temperature and pressure the maximum permis-

*Figure 9. Wearing a pocket chamber.*

sible radiation dose (industrial tolerance level) for one day, an average current of $3 \times 10^{-12}$ amperes would be produced. Such minute currents require the use of vacuum tube amplifiers and special handling techniques in order to make proper measurements. These special electronic circuits are known as *electrometer circuits.*

### 3.06 Chamber Characteristics

The characteristics of a particular radiation which enter into ionization chamber design are

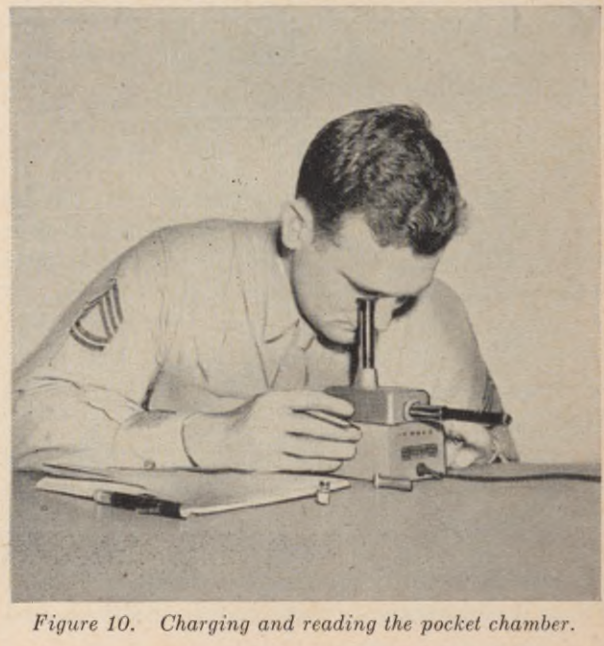


*Figure 10. Charging and reading the pocket chamber.*

the size of the source to be measured, and the range of dose rate anticipated. The physical characteristics of the chamber which can be varied to meet various requirements are—

1 Chamber Window
2 Chamber Wall Material
3 Pressure and Type of Chamber Gas
4. Chamber Volume

### 3.07 Chamber Window

Gamma rays have penetrating powers which eliminate the requirements of admission windows. This is fortunate since the greatest number of military instruments will be gamma-reading, and it is much easier to make a fully packaged instrument rugged. This is not the case with either alpha or beta particles. Beta particles are characterized by a relatively low penetrating power. Beta particles having an energy of 2 Mev have a range of slightly greater than eight meters in standard air. With aluminum as the absorber, maximum beta penetrations are roughly as shown in table II.

TABLE II.—*Range of beta particles in aluminum*

| *Energy Mev* | *Thickness* *mm* | *Thickness* *mg/cm²* |
|---|---|---|
| 0.15 | 0. 1 | 30 |
| 0.5 | 0. 6 | 160 |
| 1.0 | 1. 5 | 409 |
| 2.0 | 3. 5 | 951 |
| 4.0 | 7. 5 | 2, 035 |

It is customary in all types of nuclear work to measure window thickness in mass per unit area (mg/cm$^2$) since this gives a good practical unit of absorption that can be used for the measurement of very thin films. These thicknesses indicate that there is only a moderate problem of getting beta particles into chambers for laboratory use. The problem of making chambers with beta windows capable of rough usage is another much more difficult problem. One form of alpha-beta-gamma portable ionization chamber survey meter is shown in figure 11.

In the case of alpha particles there is considerably less penetration than with beta particles. A 5 Mev alpha particle has a range of 3.5 centimeters in air; therefore, it is readily seen that there is a real problem in getting an alpha particle into a chamber. Few windows are sufficiently thin for

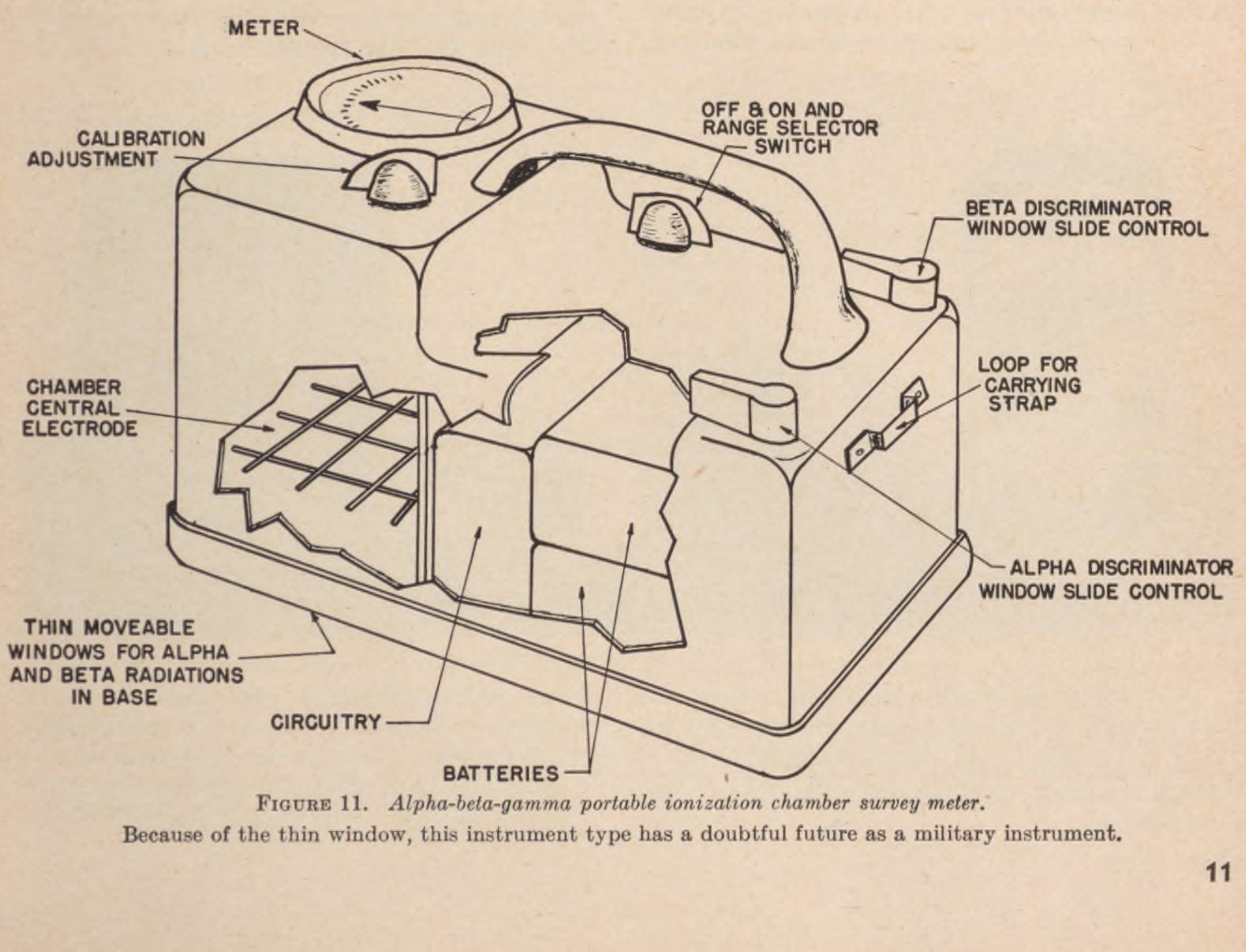



FIGURE 11. *Alpha-beta-gamma portable ionization chamber survey meter.*
Because of the thin window, this instrument type has a doubtful future as a military instrument.

alpha admission. Thin mica and stretched nylon and rubber hydrochloride films about 5 microns thick and with a mass as low as 0.5 milligrams per square centimeter have been used with some success. However, even with these extremely thin films, the alpha particle will lose from one to two centimeters of range during its penetration. It becomes apparent that alpha chambers stand little chance of developing into instruments for field use.

### 3.08 Wall Material

The wall material is of little importance to chambers devoted to alpha and beta measurements; however, the wall material becomes serious with gamma-measuring chambers since the gamma ray measurement stems from its absorption in the interior face of the chamber wall. Through the mean gamma energies of 0.5 to 1.5 Mev the various mechanisms of absorption produce a fairly uniform secondary response. The process of photo-electric absorption becomes increasingly efficient for metals at lower energies, and a metallic chamber will give readings disproportionately high when subjected to low energy gamma rays. As a result, much effort is placed into coating the interior chamber walls with nonmetals of low atomic number and writing specifications:

> " . . . . . the chamber will be air equivalent and wave length independent to within $\pm 20\%$ from 80 Kev to 1.5 Mev quantum gamma radiation."

Since the ultimate usage of these instruments is for health protection, it is desirable to have the inner wall coating approach the absorption of human tissue. Tissue is composed primarily of the light elements—hydrogen, oxygen, nitrogen, and carbon. Chamber walls therefore are made of bakelite or plastic containing a high percentage of carbon atoms or coated on the interior with a layer of colloidal carbon.

### 3.09 Pressure and Type of Chamber Gas

The thin windows required to admit alpha particles prohibit the use of any gas other than air and at any pressure other than that of the normal outside atmosphere. Little success has been found in any gas other than air for beta measurements. It should be pointed out that aircraft transportability and possible use in the air precludes the possibility of hermetically sealing at normal atmospheric pressure ion chambers having thin windows. The minute currents to be dis-

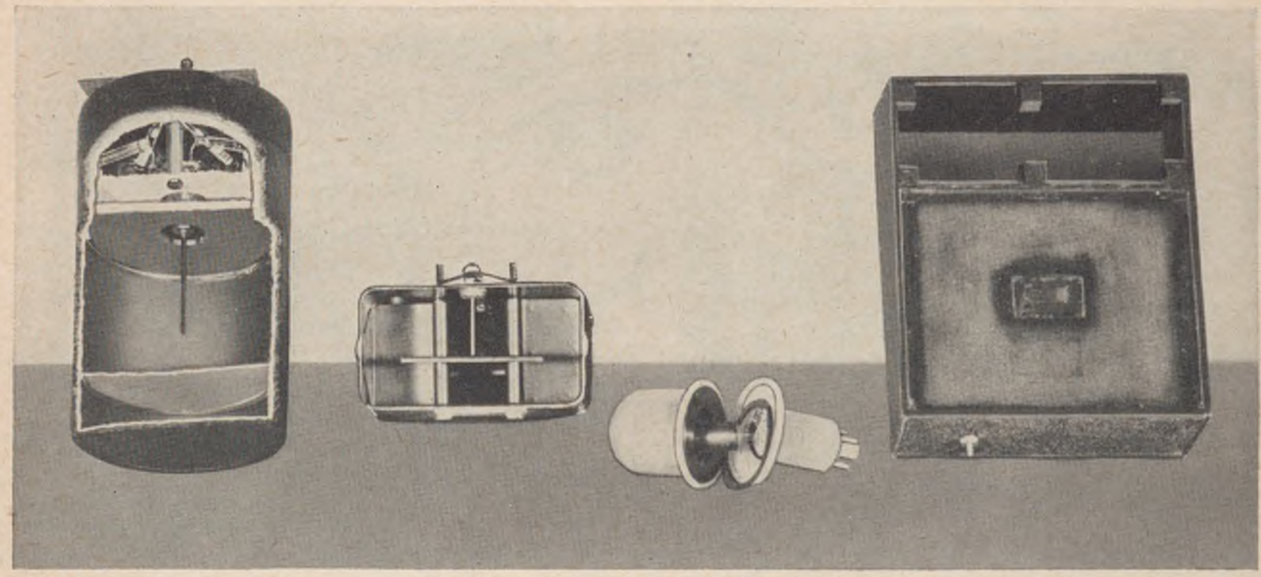


*Figure 12. Ionization chambers.*

From left to right are the ionization chambers from (a) Victoreen 247A (IM–3/PD) cut open to show the chamber interior, collecting electrode, and electrometer circuit (top); (b) National Technical Laboratory MX–6 (IM–40/PD) cut open to show the collecting electrode system; (c) Victoreen Model 300 proteximeter (AN/PDR–2) broken open with only the anode showing; (d) Kelley-Koett manufactured AN/PDR–T–1 in which the sensitive electrometer circuit is housed in a compartment adjacent to the collecting chamber. This compartment is above the chamber in the illustration.

cussed in subsequent sections indicate the necessity of maintaining high insulation between electrodes; therefore, any breather holes, to maintain equilibrium between internal and external pressure, must contain drying compounds to prevent moisture from entering the chamber.

In the case of an ionization chamber for gamma measurement, there is some point to using a gas other than air at perhaps some elevated pressure in order to increase the effective gas cross section and increase the chamber sensitivity. Freon 12 and argon have been employed in the chambers of portable instruments.

### 3.10 Chamber Volume

An increase in sensitivity is provided by an increase in chamber volume; however, with the majority of portable survey instruments, the operational desires are for smaller, more compact equipments. Three chambers from different portable survey instruments and one chamber from a group dosimeter are shown in figure 12. The physical size and shape of insulators are all that limit the smaller sizes of chambers. Large chambers are limited by the high voltage required to insure ion collection. Any type of corona discharge as the result of high voltage will produce ions which will give spurious readings.

### 3.11 Electronic Characteristics

The simplest arrangements consist of a central collecting probe through the center of the chamber as one electrode and the interior of the chamber case as the other electrode with a battery connected across the two. Under normal ionization chamber usage the negative terminal of the battery is attached to the central probe, and the positive terminal to the chamber wall (note that the reverse is true for proportional and Geiger counters). With the arrangement as shown in figure 13, it is possible to determine the voltage across the resistor $R$. Knowing the volume of the chamber, current flow can be calculated, since a radiation dose rate of one roentgen per hour causes a current flow of $9.28 \times 10^{-14}$ amperes per cubic centimeter of chamber gas volume. For example, if we consider a relatively large chamber having a volume of one litre and an extremely high resistance for $R$ of $10^{11}$ ohms; then a current flow of $9 \times 10^{-11}$ amperes will cause a voltage across $R$ of 9 volts per r/hr. This value is sufficiently high to be of some value.

In practice, the voltage is not utilized directly,

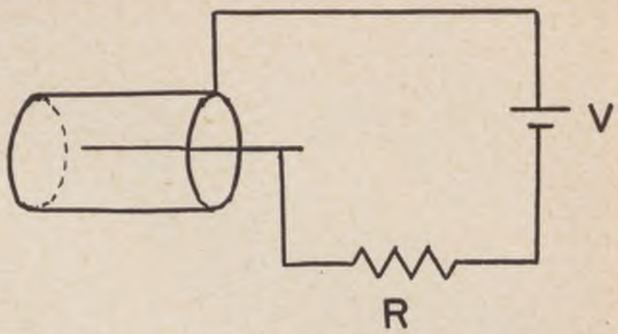



*Figure 13. Ionization chamber circuit.*

since it is not possible to make measurements across resistors having values of the order of magnitude of $10^{11}$ ohms In addition, if our example were taken in the range of daily tolerance intensities, say 4 milliroentgen per hour (0.004 r/hr), the potential drop across $R$ would be 0.037 volts. Vacuum tubes therefore are required as a means of amplifying voltage and currents of this order of magnitude.

The common types of vacuum tubes have been rejected for ionization current amplifiers. The normal tubes have an extremely small flow of current from grid to cathode, known as the grid current, which may be of the order of magnitude of $10^{-9}$ amperes. However, $10^{-9}$ amperes when allowed to flow through a resistance of $10^{11}$ ohms will produce a potential drop of some 100 volts. *Electrometer tubes*, specifically designed with grid currents of $10^{-15}$ amperes or less are being manufactured for use in ionization chamber instruments. Low grid currents are obtained by operating the tubes at low filament temperature and by placing screen grids between the filament and control grid. These screens are at a very slight positive potential so as to collect the electrons normally surrounding the cathode. A group of electrometer tubes are shown in figure 14.

In addition to the low grid current characteristics, the electrometer tubes are designed to insure extremely low leakage currents. These currents are held to a minimum by operating the tube at low plate voltage and current. Extreme care must be taken in the handling of electrometer tubes, since body oils deposited on or near the tube base may cause serious leakage currents.

Special manufacturing techniques also are required to produce resistors up to $10^{14}$ ohms. Five such resistors, carefully sealed in glass, are shown in figure 15.

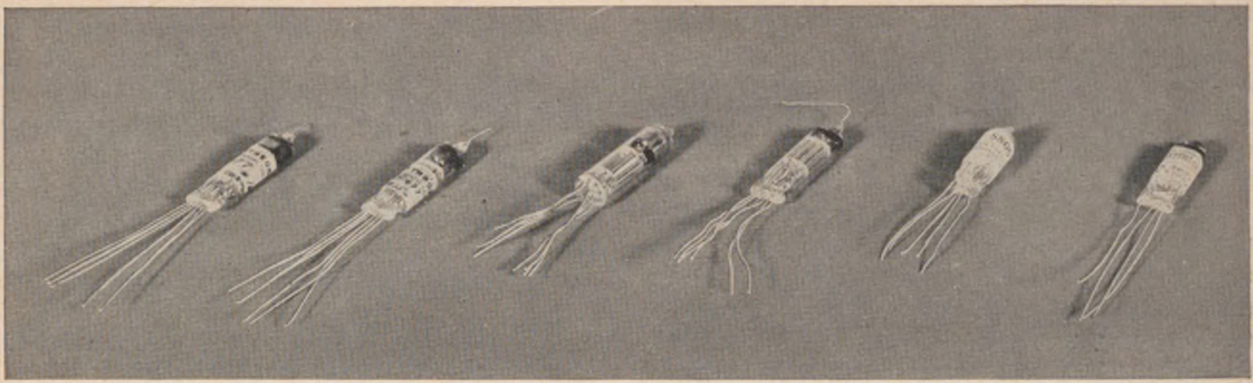


*Figure 14. Electrometer tubes.*

Shown is an assortment of subminiature triode, tetrode, and pentode electrometer tubes which are used for the amplification of the minute currents produced by radiation in ionization chambers.

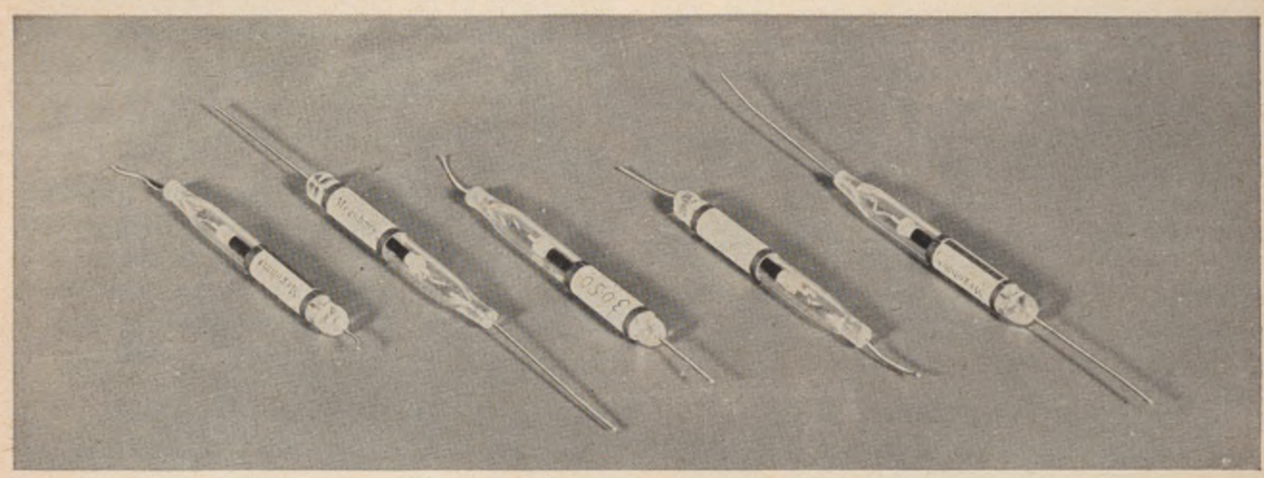


*Figure 15. Resistors for electrometer circuits.*

Shown is an assortment of resistors having values of $10^8$ to $10^{14}$ ohms. The resistor is inclosed in a glass envelope 1⅞ inches long and 0.2 inches in diameter.

### 3.12 Ionization Chamber Instruments

Radiac instruments, sensitive to gamma radiations, with 30 to 50 cubic inch chambers are useful as light weight, high dose rate measuring instruments for field survey work. Such an instrument is shown in use in figure 16, and diagramatically in figure 17. This is perhaps the most important of all military radiation survey instruments. Thin window survey chambers as previously discussed in connection with figure 11 may be used to measure gamma radiation and give indications of alpha and beta radiations. Ionization chambers have many uses such as in the small pocket dosimeters and chambers for individual dosage measurements and with larger chambers for group dosage recording devices.

*Figure 16. An ionization chamber survey meter goes ashore during landing maneuvers.*

## Chapter 4

# GAS AMPLIFICATION

Ionization chamber voltages are relatively weak. However, if higher voltages are applied to the chamber electrodes, a gas amplification can be obtained (5). When the electron from an ion pair is given greater energy than the ionization energy of the atom or molecule of a gas, it may produce additional ionization as shown diagramatically in figure 18. Gas amplification also can be obtained by reducing the energy required to ionize the chamber gas through the choice of a suitable gas or by decreasing the chamber pressure so as to increase the mean free path and the energy of the ionizing particle.

If we consider the counting chamber and circuitry as shown in figure 19 with the chamber exposed to a constant energy source of radiation, each particle entering the chamber will produce a definite number of ion pairs, and these ions will be collected at the electrodes, thereby producing a pulse of current in the external circuit.

If the size of the pulse is plotted as a function of the voltage applied to the electrodes, a curve such as that shown in figure 20 is formed.

Below a certain minimum voltage across the chamber we do not collect all the ions which are formed, because in this region of low voltage, *0–a*, ions have an opportunity for recombination prior to collection. At slightly increased voltages, *a–b*, normal ionization chamber working conditions are reached. Above voltage *a* the pulse size becomes relatively independent of the voltage, since there is a complete collection of all ions formed by the

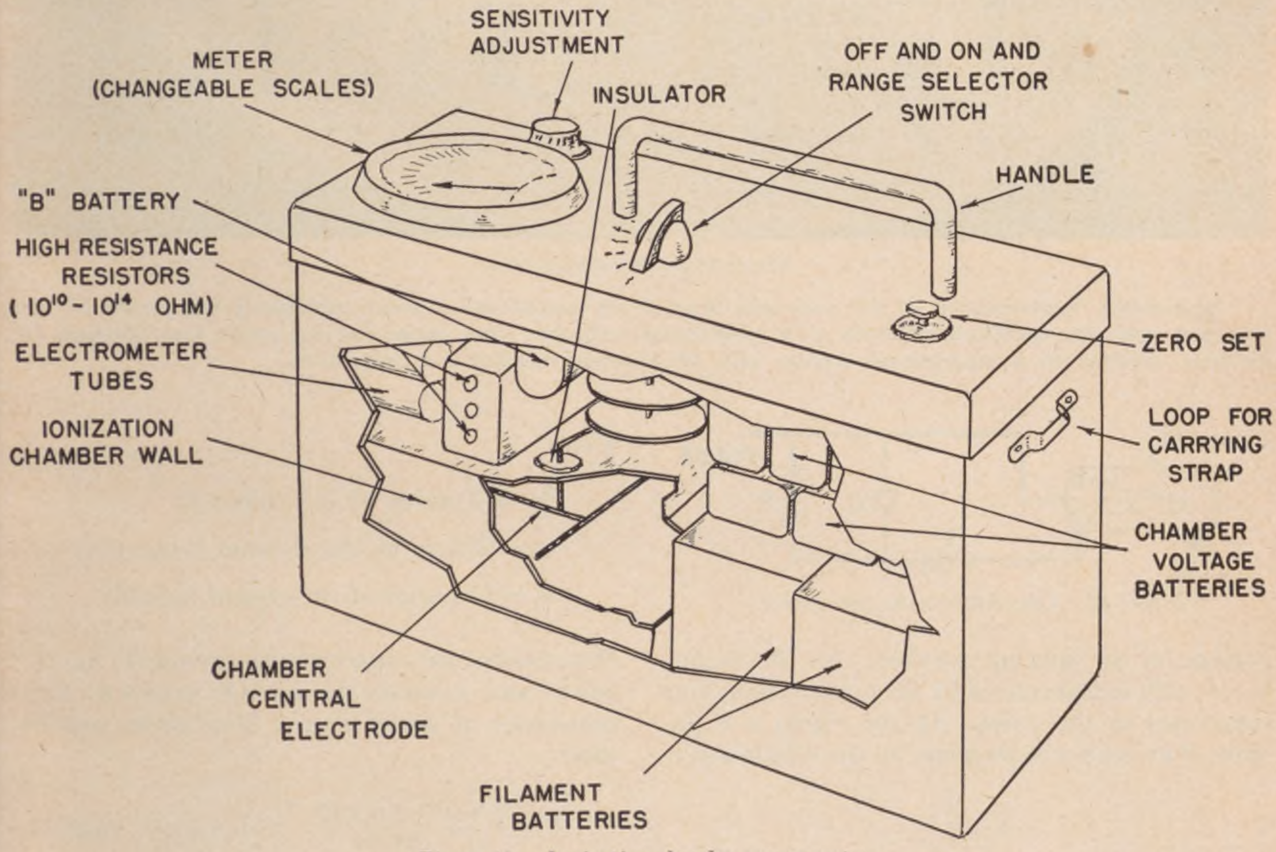



*Figure 17. Ionization chamber survey meter.*

Gamma-measuring instruments of this type are probably the most important military survey instruments.

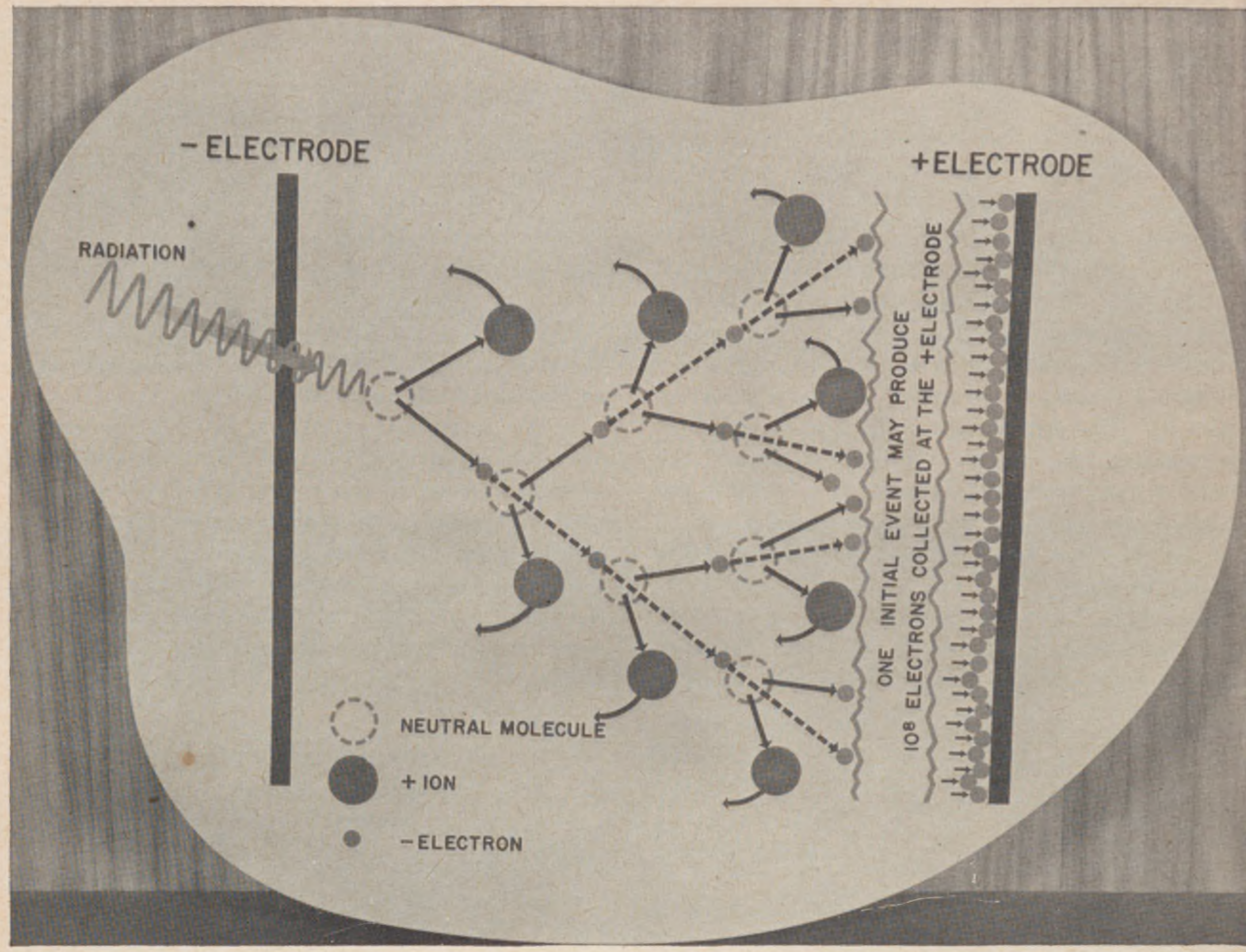



*Figure 18. Gas amplification.*

Diagramatic representation of the avalanche type of gas amplification found throughout the Geiger-Mueller tube and near the collecting electrode of a proportional counter. One initial ionizing event may produce $10^3$ electrons collected in a proportional counter and $10^8$ electrons collected in a Geiger-tube.

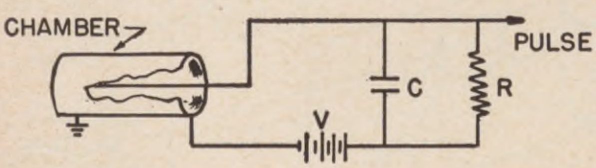



*Figure 19. Counting chamber and circuit.*

passage of an ionizing particle. In the region *0–a–b*, only ions produced by the primary radiation contribute to the pulse. In the region *a–b* the pulse P in volts will be given by the relationship:

$$P=\frac{Nc}{q}$$

where:

N = Number of ions collected

c = Charge on the electron (coulombs)

q = Capacity of the system (farads)

If we assume the capacity of the system to be $10^{-11}$ farads and examine the voltage produced by 1 centimeter of travel of a 1 Mev alpha particle, then:

$$P=\frac{(4\times10^{4})(1.6\times10^{-19})}{10^{-11}}=6.4\times10^{-4}\text{ volts}$$

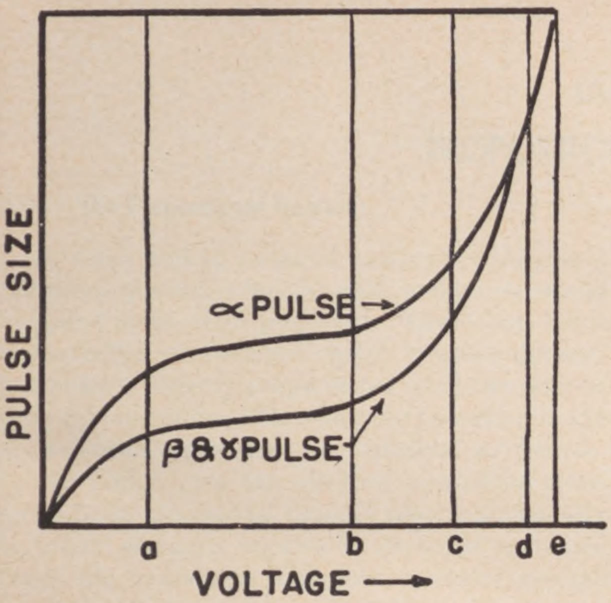



*Figure 20. Pulse size as a function of voltage from a chamber exposed to a constant energy source of radiation.*

*a–b* Ionization chamber region
*b–c* Proportional region
*c–d* Limited proportional region
*d–e* Geiger region
above *e* Continuous discharge region

The same length of travel with a 1 Mev beta particle:

$$P = \frac{(30)(1.6 \times 10^{-19})}{10^{-11}} = 4.8 \times 10^{-7} \text{ volts}$$

One would expect a slightly larger voltage, say $4 \times 10^{-7}$ volts to be produced as the result of the secondary electron produced in the absorption of a 1 Mev gamma ray. Assuming photoelectric absorption of the gamma ray, some energy is required for ionization, some energy will perhaps go into kinetic energy of the products of ionization, and there may be some excitation of other electrons in the ionized atom. At any rate, it would be expected that the photoelectron would be produced with very slightly less energy than the 1 Mev beta particle and because of its lower velocity (see page 4) will produce a slightly greater number of ion pairs per centimeter of travel in the chamber. If the chamber is such as will expend all the energy of the beta particle or photoelectron, the total number of ion pairs produced by the beta particle will be slightly in excess of those produced by the gamma ray photoelectron.

# Chapter 5

# PROPORTIONAL COUNTER

## 5.01 The Proportional Region

At some higher voltage *b* in figure 20 the above relationship would cease to exist, and pulses would be found larger than predicted. The region *b–c* is the so-called *proportional region*, because the output pulse is directly proportional to the amount of primary ionization. The chamber operation in the proportional region can be explained as follows: In the region of a few electron mean free paths away from the central (anode) wire, a sufficiently high field strength imparts to electrons, attracted from the remaining chamber volume, enough energy to cause secondary ionization. The output pulse is therefore increased by the collection of the additional electrons and is proportional to the magnitude of the initial ionizing radiation.

If there are I ion pairs formed by collections as an electron travels toward the central electrode, then the size of the voltage pulse is given by—

$$P=\frac{(I)(1.6\times 10^{-19})}{q}$$

Here, "I" is defined as the gas amplification and is the ratio of the number of electrons collected at the anode N to the number of ion pairs originally formed in the gas $N_o$:

$$I=\frac{N}{N_o}$$

It should be noted that the gas amplification factor varies from about 10 in certain photoelectric cells to $10^3$ in proportional counters and to $10^8$ in some Geiger-Mueller counter tubes as shown in the diagram in figure 18.

In the case of the proportional counter it is necessary that the secondary ionization (or amplification) occur less than ten electron mean free paths from the central wire. Otherwise strict proportionality ceases, and the *limited proportional region c–d* is entered where the gas amplification factor has values from $10^4$ to $10^7$.

Since the total ionization produced by an ionizing particle is dependent on the type of particle, it follows that in the proportional counter region we are able, within limits, to differentiate between the pulses produced by alpha particles and the pulses produced by either beta or gamma radiations. This means that the proportional counter will have a limited military usage for alpha measurements. If the field strength is such as to form a beta-gamma to alpha ratio of $10^5$ or greater, such as roughly approximates the case immediately following an atomic bomb explosion, the proportional counter is not capable of differentiating between the combined effects of a multitude of smaller beta and gamma pulses and the large alpha pulses. The proportional counter has a definite use in decontamination work after the decay of the short half-life gamma and beta emitters. A portable proportional counter survey meter is sketched in figure 21.

Certain factors must be considered in order to establish good working characteristics for proportional counters. The gas used for tube filling may be chosen so as to accomplish the desired action. Pure argon, helium, neon and methane, and certain combinations of these gases have been found to give satisfactory results. Other counter probes are left open to the air. Strong electric fields may be produced with moderate voltage by using two coaxial cylinders as the electrodes, and since the field strength varies logarithmically for a cylindrical configuration, the smaller the diameter of the anode, the higher will be the field strength in the vicinity of one electron mean free path of the wire. For this reason, extremely fine central electrode wires are employed. It is readily seen that the mechanical strength of a thin window tube with a 0.0005 inch diameter central wire is not such as to lend itself readily to field use.

## 5.02 Proportional Counter Probe

As previously stated, a counter for use in the proportional counter region is restricted in the multiplication of electrons to somewhere in the order of ten generations. This can be obtained in the large electric field near the central wire in the cylindrical arrangement described above. It follows that a parallel plate structure is excluded

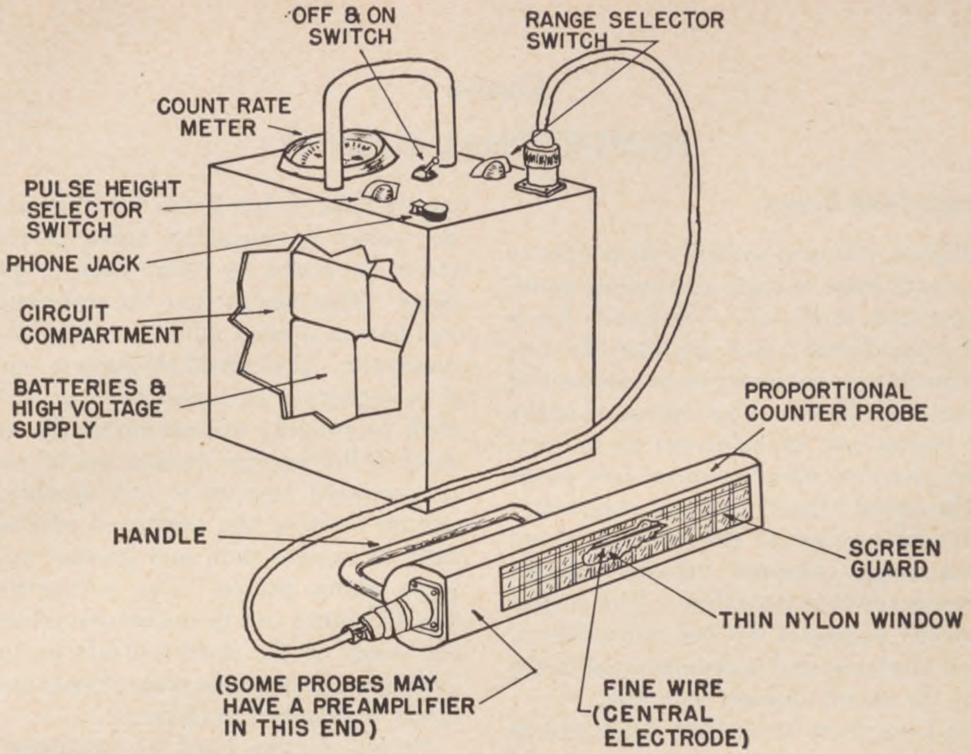



*Figure 21. Portable proportional counter survey meter.*

This type of instrument will be used for alpha particle detection.

for use in a proportional counter. It is possible to build proportional counter probes with large windows using a number of parallel wires. A satisfactory geometrical configuration has been found where the depth of the chamber behind the window is "x", the wires are placed at a depth "x/2" and a distance "x" apart. In some probes, "x" has been chosen equal to one centimeter. Such a multiple wire probe is shown in figure 22. A single wire probe is shown in figure 21. In this latter example the probe case is not completely cylindrical since the window opening is cut longitudinally along the side wall.

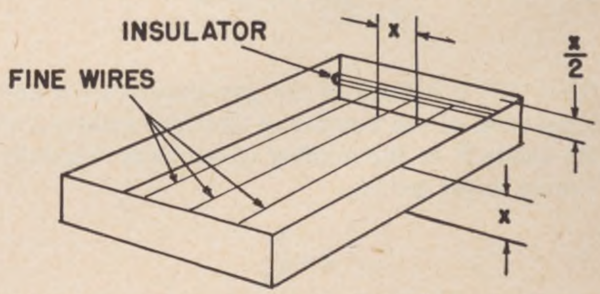



*Figure 22. Parallel wire proportional probe.*

A satisfactory geometrical arrangement has been found with x=1 inch.

Parallel wire counters having large sensitive openings (100—150 cm$^2$) are used for the survey of large areas. Proportional counters with probes are used for checking alpha contamination on hands, feet, clothing, filter paper samples, and various surfaces. This is primarily a tool used in conjunction with a field laboratory and with decontamination activities.

## Chapter 6

# GEIGER-MUELLER COUNTER

### 6.01 Avalanche Ionization

If in our previous example (fig. 20) the voltage is raised still further above point *c* the gas amplification factor will continue to increase, but in the region *c–d*, the amplified pulses are no longer proportional to the initial ionization. This means that secondary ionization is started outside the distance of a few electron mean free paths from the central wire. There is still some difference in final pulse sizes so that this region *c–d* is known as the *region of limited proportionality*. Tubes operated in this region have little application outside research laboratories.

If the voltage is increased still further, a new phenomenon occurs in which secondary ion multiplication spreads throughout the entire chamber volume. This cumulative effect is known as *Townsend* or *avalanche ionization* and is shown diagrammatically in figure 18. When a chamber is used in this region *d–e*, it is called a *Geiger-Mueller counter*, and the pulse size is independent of the event which initiated it. Still higher voltages produce above point *e* a *region of continuous arc discharge*. While in effect this is not a continuous discharge but a series of pulses so closely spaced to give that appearance.

It should be noted that for any particular counter tube, if the pressure is held constant and the voltage is varied the instrument can be made to operate as either an ionization chamber, proportional counter, or Geiger counter. By holding the voltage constant a similar situation can be created by varying the mean free path through variations in gas pressure.

An examination of pulses from a Geiger-Mueller tube reveals that pulses are of the same size only when spaced a good time apart. One would expect all pulses to be of the same size, but an examination of the action of the positive ion reveals that this is not always the case. In previous discussions of the operation of ionization chambers and proportional counters we have neglected the effect of the positive ions and considered only the action of the electrons. Because of their mass, the positive ions move slowly under the influence of the electric field reaching the outer collecting electrode in perhaps $10^{-3}$ seconds. The electrons formed during the Townsend avalanche, being many orders of magnitude ($10^4$) lighter, are all collected in less than $10^{-6}$ seconds, which is a long time before the positive ions reach the cathode. The result is a cloud of positive ions forming at a distance of several mean free paths from the anode and moving toward the cathode. This produces a positive space charge which for a time completely shields the anode and prevents counter action. As the positive charge moves closer to the cathode, a limited counter action is allowed to occur. In this case the initial pulse will be of greater magnitude than that of the one which follows. An examination of the pulse delivered by a Geiger-Mueller tube may be made with the help of figure 23.

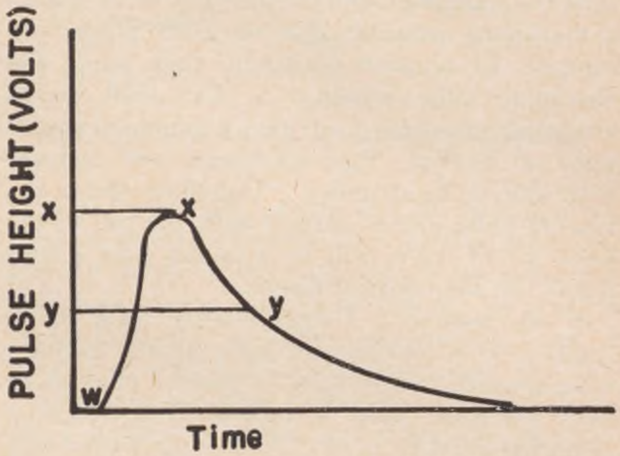



*Figure 23. Geiger-Mueller tube pulse.*

After one pulse has started at *w*, no second event can take place until the pulse reaches *y*. The time *w–y* is the tube *dead time*.

The pulse develops rapidly from *w* to *x*, due to the rapid collection of electrons. The pulse decays more slowly from *x* to *z*, due to the longer transit time of the positive ions and the time constant of the external circuit. After one pulse has started at time *w*, no second event can take

place until the pulse has reached $y$, due to the shielding action of the positive space charge. The time $w$–$y$, in which no second event can take place, is called the tube *dead time*. This time is very important, because it determines the maximum counting rate of the tube and its allied circuit. In portable survey instruments the dead time is approximately 0.0005 second which allows a maximum counting rate of 2,000 pulses per second. It becomes apparent that since the maximum tube response is $Vx$; then pulses occurring after time $y$ will have a minimum amplitude of $Vx$–$Vy$. This amplitude will increase with time to $Vx$ at time $z$. Therefore, during the time of pulse decay starting with the end of the dead period, there will be a period $y$ to $z$ with pulses less than normal height.

If we assume a Geiger-Mueller tube to be exposed to a constant intensity source having a wide spectrum of energies of gamma photons or beta particles; then a typical Geiger-Mueller tube characteristic curve of pulses per second as a function of voltage may be plotted in figure 24.

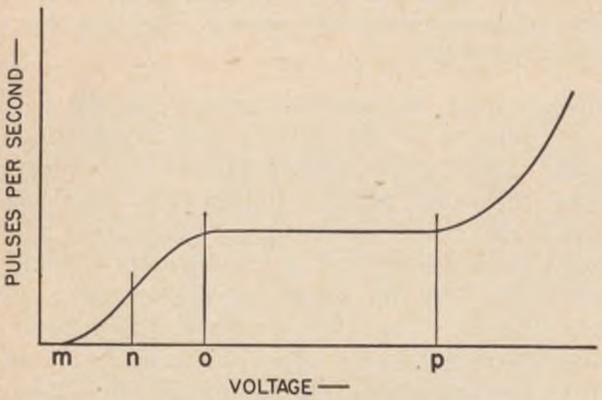



*Figure 24. Geiger-Mueller tube characteristic curve.*

- *m* Curve threshold
- *m–n* Region of proportional counting
- *o* Threshold of Geiger region
- *o–p* Plateau
- *p* Start of continuous discharge region

There will be no response to the small pulses in the ionization chamber region where there is no gas amplification. A threshold $m$ appears early in the proportional region. This region extends from $m$ to $n$. As the voltage is increased, the gas amplification becomes increasingly more important with more of the less energetic particles being counted. At $o$ the *threshold* of the G*eiger region* $o$–$p$ is reached, and within the resolving time of the tube practically every particle entering the tube which is capable of producing at least one ion pair in the tube gas is counted. Beta particles which penetrate the tube walls will be counted with almost 100% efficiency; on the other hand, gamma rays must produce ionization in the tube in order to be counted. The gamma counting efficiency usually is considered less than one per cent. The region of continuous discharge begins at $p$.

The Geiger portion of the characteristic curve $o$–$p$ is known as the *plateau*. It is desirable, particularly in portable battery operated survey meters, to have a long, flat plateau; since the counting rate does not depend on applied voltage and, within limits, will not be affected by battery aging. Tubes having plateau lengths from 100 to 300 volts and slopes showing an increase in counts of only one to two per cent for a change of 100 volts are in general usage. In many portable survey instruments these tubes operate with the threshold of the Geiger region in the neighborhood of 900 volts. In the laboratory equipment various tubes operate up to 2500 volts. Most of the portable radiac instruments are necessarily restricted to batteries, and the higher the voltage, the larger and heavier the battery requirements. Efforts are under way to develop satisfactory high voltage supplies* which operate from low voltage batteries. This is only a temporary expedient until satisfactory low voltage Geiger-Mueller tubes are developed. Constant voltage power supplies will reduce the requirement for a long plateau although tube aging with use many times causes voltage shifts in the characteristic curve which makes the plateau desirable.

## 6.02 Quenching the Discharge

The approach of the positive ion cloud to the cathode cylinder will result in pulling electrons from the cathode to produce neutral atoms or molecules. The electron usually enters combination with the positive ion in an excited state. The process of transit to the ground state produces a characteristic series of spectral radiation, and some of these radiations will be in the ultra-

*There are essentially nine different types of power supply which can be used to provide the high voltage required for Geiger counter operation: Battery, condenser, condenser-commutator, vibrator, condenser-vibrator, radio frequency, fly-back, transformer (AC supply), and multiplier (AC supply).

violet region. This ultra-violet radiation usually has sufficient energy to produce photoelectron emission from the cathode. These photoelectrons, in turn, will have sufficient energy to start a second avalanche, and the whole process will be repeated. It is therefore necessary to construct counters in which the cycle is halted for each individual pulse. This process is called *quenching* and can be accomplished by using external electronic methods or by using special vapors inside of the counter tube.

All external quenching methods work on the principle of lowering the collecting electrode voltage below that at which the counter can form an avalanche until such time as the danger of an additional avalanche is passed (3) (5). The recovery time for resistance quenched circuits is in the order of $10^{-2}$ seconds. The Neher-Harper circuit, a good example of vacuum tube quenching, is shown in figure 25. This circuit has a recovery time in the order of $10^{-4}$ seconds.

When current flows as the result of a discharge of the detector, the resistor $R_1$ raises the vacuum tube grid potential. As the grid becomes positive from its normal $-4.5$ volt bias, the tube conducts, thereby dropping the potential on the collecting electrode. Other quench circuits in use are the Neher-Pickering, Getting multivibrator, and a number of combinations and variations.

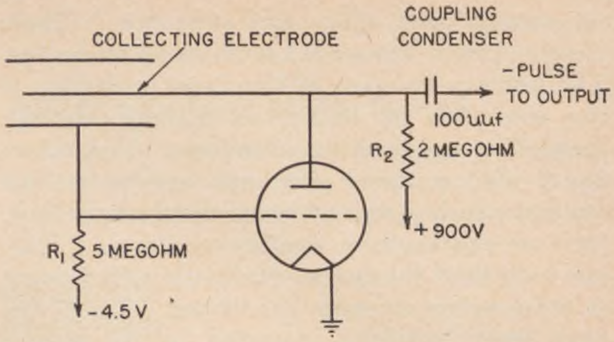



*Figure 25. Neher-Harper vacuum tube quench circuit.*

Internally quenched Geiger-Mueller tubes utilize small amounts of polyatomic vapor such as ethyl ether, amyl acetate, ethyl alcohol, etc., mixed with the regular tube gas in order to cause the detector

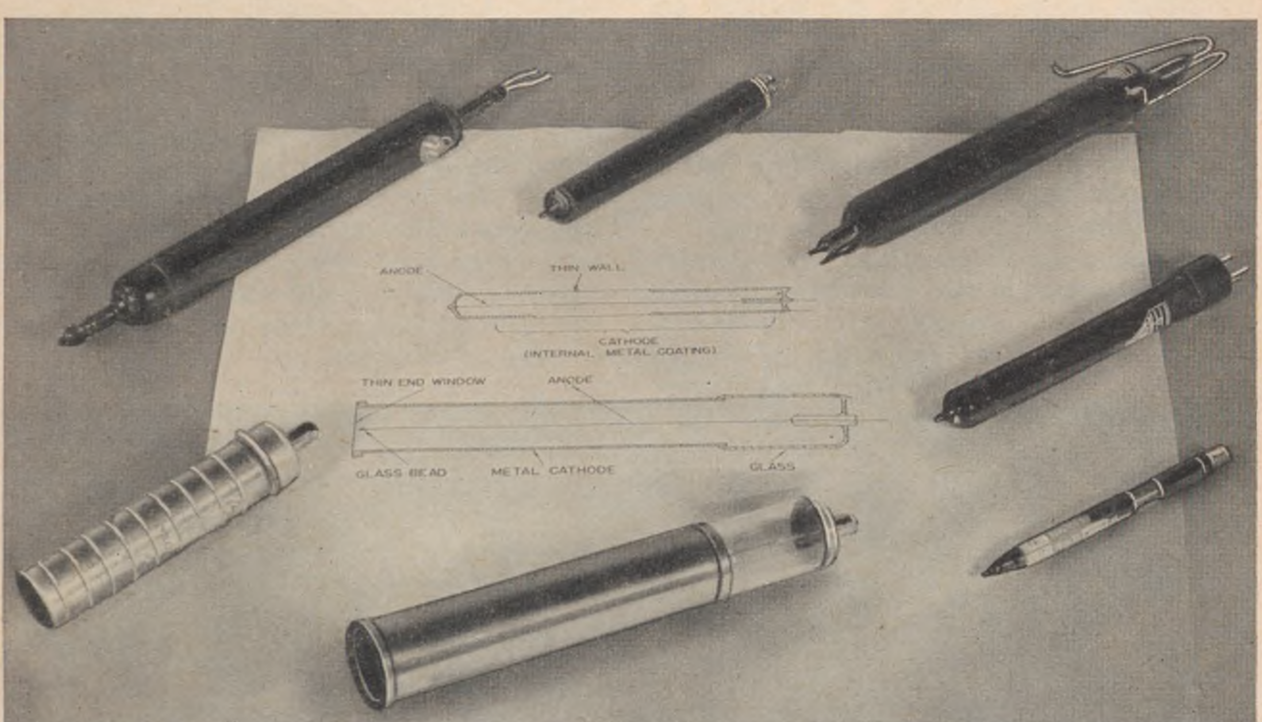



*Figure 26. Tubes for portable Geiger-Mueller counters.*

The diagram indicates the difference between thin wall and thin end window tubes. The Victoreen all metal thyrode 1B85 is shown in the lower left. The thin-end window tube is the BS–1 used for beta-gamma indication in the AN/PDR–8 series, –15 and –27. The BS–2 for high range gamma detection in the same instruments is shown in the lower right. An assortment of thin-walled tubes from other portable counters is shown.

to quench itself after each discharge. These Geiger-Mueller tubes are known as *self-quenching*. The primary function of the vapor molecules is the absorption of ultra-violet photons, thereby forestalling any repetitive discharge. The majority of the quenching gases are complex organic molecules such as alcohol or xylene which preclude their use under subzero weather conditions. They also may show changes in sensitivity with changes in temperature at room conditions. One of the most severe problems presented by the quench vapor is in limiting the life of the tube. Some of the quenching vapor is dissociated at each discharge, and eventually the vapor is completely used up and the tube goes into a repetitive discharge condition. The better tubes in survey equipment will have a life of 3 x $10^9$ counts. For continuous operation in a field which will just allow utilizing a $10^{-4}$ second resolving time, the tube life will be only 100 hours.

Considerable work is under way toward the development of Geiger-Mueller tube fillings which will overcome the difficulties that have been enumerated above. Halogen gas mixtures are among the most promising. Tubes have been constructed with the Geiger threshold in the neighborhood of 700 volts, having a virtually flat plateau of several hundred volts. These tubes appear to have good temperature characteristics and a life well in excess of that for tubes generally employed in survey equipment.

The majority of Geiger-Mueller counter tubes presently employed in survey meters are ⅞ inch in diameter and 5¾ inches long. The cathodes vary from one to three inches in length. In common use are thin side walls of 30 mg/cm² thickness. Others have thin end windows in some cases 3 mg/cm² thick. Such tubes are shown in figure 26. Laboratory counter tubes range up to 3½ inches in diameter with the length from two to ten times the diameter. Several laboratory Geiger-Mueller tubes are shown in figure 27. The anode, thoroughly insulated from the cathode, is a fine wire from 0.0001 to 0.0010 inch in diameter running down the cathode cylinder axis. To obtain a satisfactory characteristic curve, the central wire must be manufactured carefully, free of die marks and sharp protuberances. The tube must be cleaned carefully to remove all dust, grease, water vapor, and oxygen; and special care must be exercised in the selection of pure filling gases. In addition, the filling gas pressure must be chosen carefully. Most tubes used in radiac equipment of the portable survey type incorporate thin windows to permit some beta counting. Normally, this is a cylindrical section of tube wall approximately 2 inches long at mid-tube length as shown in figure 26 and having a thickness of 30 mg/cm². Provided the probe housing tube does not add additional shielding, the tube then will be sensitive to beta particles having energies above 0.16 Mev. As previously stated, counter tubes may be employed with thin end windows such as that illustrated in figure 26. Tubes of this type of construction are in more common use in laboratory equipment than in equipment used for field survey work. Mica windows down to 0.5 mg/cm² are available, although in normal laboratory work the thin windows run between 1.5 and 4 mg/cm² in thickness.

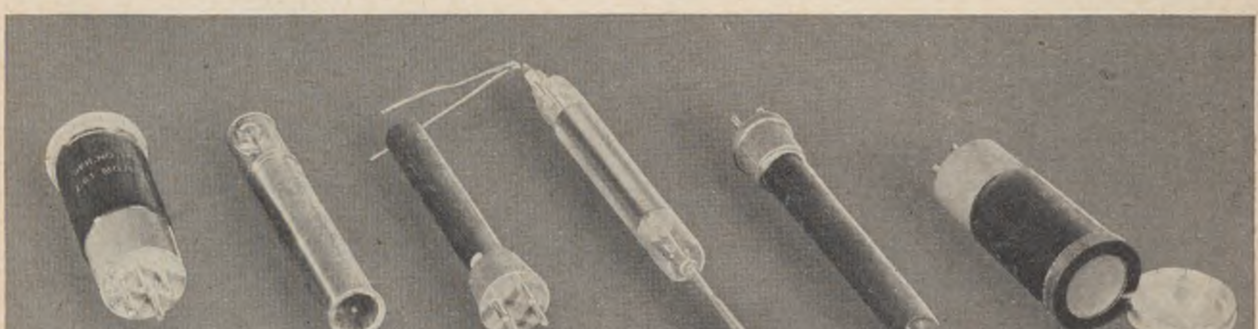


*Figure 27. Laboratory Geiger tubes.*

A number of tubes have been developed to cover the wide range of requirements of laboratory counting.

A great majority of Geiger-Mueller tubes are photosensitive. This undesirable feature has been overcome by coating the glass envelope with an opaque surface. Occasionally, pin holes in the thin opaque coating will cause spurious counts when the tube is exposed to bright sunlight. In addition, the opaque coating has been known to peel off a once satisfactorily operating tube and introduce serious counting errors.

### 6.03 Portable Geiger-Mueller Detector

Geiger-Mueller counters, utilizing self-quenching tubes, are especially useful as light weight highly sensitive detecting instruments for field

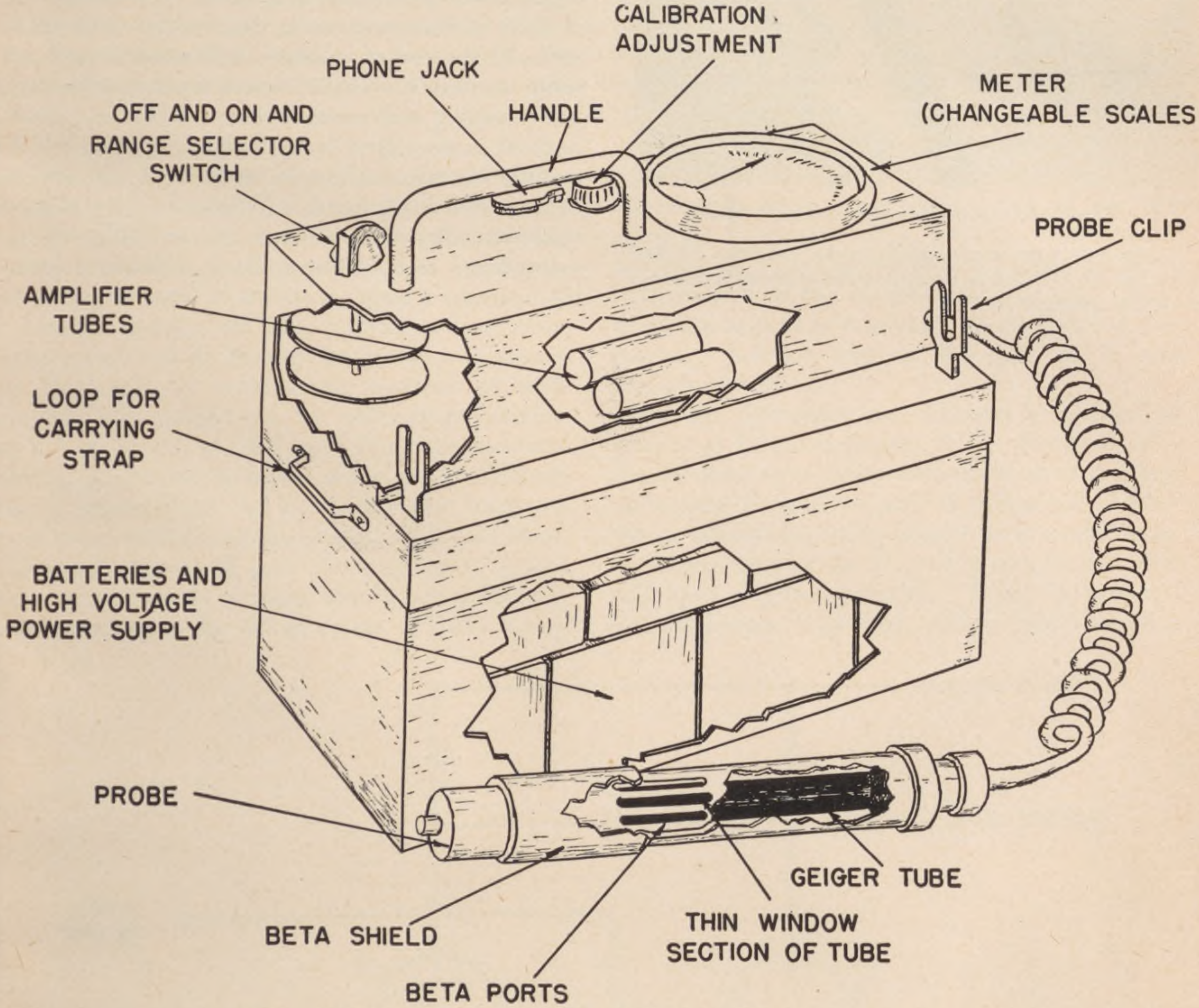



*Figure 28. Diagramatic sketch of a portable Geiger-Mueller survey meter.*

The probe, foreground, has a descriminating slide which may be used for beta indications. Indication is by the meter and by headphones (not shown).

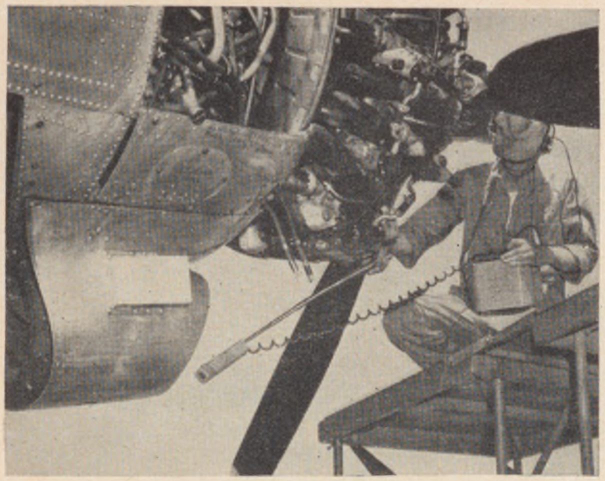


*Figure 29. Geiger-Mueller counter in use.*

A *fish-pole* type of extended handle has been utilized with the AN/PDR–8 to hold the tube probe at a distance from the operator's body.

survey and decontamination work. Such an instrument is shown in figure 28. The pulses are of such magnitude that they can be heard in earphones without the necessity of much external amplification. At low intensity levels, a few multiples of ordinary background (30–50 counts per minute—roughly 0.01 mr/hr) aural indications are found in many cases to be more useful than observation of an indicating meter. The majority of field instruments place the counter tube in a probe at the end of a three- to five-foot length of cable so that the larger, heavier case containing power supply electronic circuitry, meter, etc., can be held in one hand or by a shoulder strap while a detailed examination is made with the probe held in the other hand. A *fish-pole* type of extended handle, which has been utilized with certain instruments to hold the probe at a distance from the operator's body, is shown in figure 29.

## Chapter 7

# SCALING CIRCUITS

Field laboratories will be used to evaluate samples of terrain, food, water, etc., to determine the nature and extent of radiological hazards. This work requires that accurate counts be made. The best mechanical counters can be driven at rates of perphaps no more than 300 times per second; therefore, other means are required to record the maximum Geiger-Mueller count in the neighborhood of 5,000 pulses per second. Electronically, it is possible to record pulses at rates far in excess of the best counter tube output. Some of these electronic arrangements are known as *scaling circuits.*

Scaling circuits are based upon a basic two-tube circuit which divides the number of pulses by two, and by constructing a series of such circuits, the pulses can be reduced by factors of 2, 4, 8, 16, 32, 64, 128, etc. The most common scaling circuits in use utilize scales of 64. Recording is accomplished by neon indicator lamps at each stage multiple of the circuit. The sum of all indicator lamps will give the number of pulses counted. Since 64 or more counts per second are not uncommon, the circuit is set to drive a mechanical register which records the total number of 64 counts which have taken place. A greatly simplified scale of two scaling circuits is shown in figure 30. Essentially, the two plates are joined by a relatively large capacitor $C_1$ of the order of 0.1ufd. The two cathodes are tied together through the identical resistors $R_1$ and $R_2$ and held at some small negative bias. Because of the cross coupling by capacitor $C_1$, the circuit will be in equilibrium when either tube is cut off and the other at maximum plate current. An impulse having fired $T_1$ causes the grid of $T_2$ to go negative with respect to the cathode and not fire. However, the arrival of a second impulse gives a momentary positive bias to the grid of $T_2$ and accordingly it fires.

Certain difficulties are inherent in translating powers of 2 into multiples of 10; therefore, electronic circuitry is being devised to give readings of decades (units of 10), and all military field laboratory equipment will probably be so constructed.

Scaling circuits can be used in conjunction with any type of pulse detection. Many instruments are constructed with high voltage power supplies

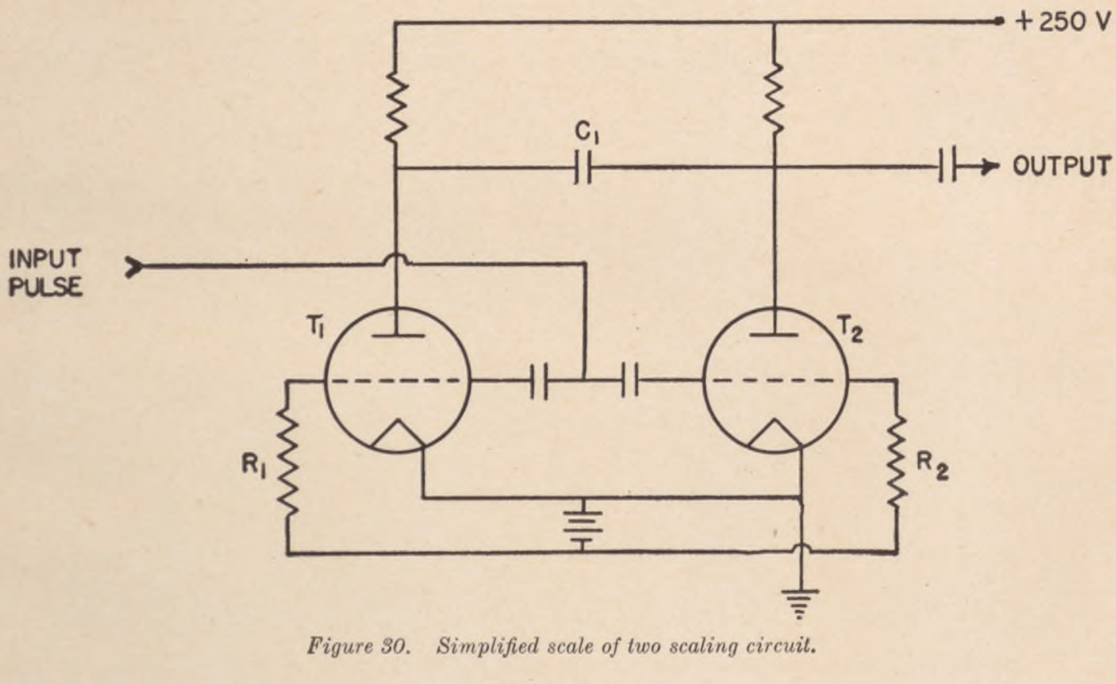



*Figure 30. Simplified scale of two scaling circuit.*

which may be varied for proportional or Geiger counter action. Scalers are built with special parallel plate chambers for alpha counting, and with proportional counters having a continuous flow methane atmosphere for counting alpha particles in the presence of high beta and gamma activity.

Occasionally in specialized fields of research such as the investigations of cosmic rays one may wish to record a count only when two or more tubes are discharged simultaneously or when one tube of a set does not discharge. Many circuits have been devised to provide the required discrimination and are known as *coincidence* and *anticoincidence circuits*. These circuits have received considerable description in technical literature but have little potential use in military radiological defense and are mentioned to assist the reader with terminology.

## Chapter 8

# COUNT RATE METER

The normal portable Geiger-Mueller survey meter uses a count-rate meter in addition to aural indication of pulses. This meter simply reads the rate of arrival of pulses and with rates above ten times normal background the rate is rapid enough so that a steady meter reading is obtained. In laboratory equipment it frequently is convenient to use a count-rate meter in place of a scaling circuit. Considerable effort is placed in circuitry to provide the meter with pulses of the same size so that all pulses give identical contributions to the meter reading.

Count-rate meters can be used to indicate the rate of arrival of almost any type of pulse. Many laboratory instruments are constructed with variable voltage supplies that may be used with counting chambers, proportional counters, or Geiger counters. The laboratory count-rate meters usually are provided with terminals so that the counting rate may be fed into some type of moving paper recorder. In this manner sample decay characteristics may be obtained by recordings made over a period of time.

External quenching methods, such as the Neher-Harper circuit previously discussed in connection with figure 25, can be employed in conjunction with laboratory scalers and count-rate meters. Space and weight considerations prohibit the use of external quenching circuits with portable equipment. Objections to use with portable equipment may, in the future, be overcome by the use of miniaturized circuits.

# Chapter 9

# CRYSTAL AND CHEMICAL DETECTION

## 9.01 Excitation

As previously shown, an electrically charged particle in its passage through a gas may come close enough to an atom to exert sufficient force to remove an electron and ionize the atom. In many cases the charged particle will not exert enough energy to cause ionization, but will cause one or more of the atom's electrons to be raised to higher energy levels. The excited atom in returning to its ground state will radiate a characteristic series of spectral lines. Some liquids or solids subjected to ionizing radiation may give off a characteristic fluorescence which can be measured. In addition, the free electrons produced in a solid or liquid by ionization may cause changes in the electrical conduction of the substance in which they are produced. This latter process is sometimes referred to as *photo conduction*.

Some crystals do not return immediately to a ground state after being exposed to radiation. This may manifest itself in a crystal color change. In some cases shining light on the crystal will release energy which has been trapped in the crystal excited stage. Some crystals will encounter an effective change in electrical resistance when subjected to ionizing radiation. In some cases chemical reactions which produce color changes are initiated by the disassociation of compounds, formation of free radicals or electron attachments under the influence of radiation. With the exception of photographic film badges, which will be discussed later, these various phenomena are of interest only in that some day they may be incorporated into a military dosage measuring device. Much developmental effort is being placed on a dosage indicating tag which will change colors at various levels of exposure so as to be used for rapid determination of the degree of field exposure.

## 9.02 Chemical Dosimeters

It appears possible to detect nuclear radiations by methods depending upon chemical change induced by radiations. Detection of radiation by chemical reactions possesses a possible advantage over detection by other methods of instrumentation, in that a single chemical method may be used to detect radiation over a wide range of intensity from a fraction of a roentgen to over 1,000 roentgens. The problem involved in such a method of detection is that of finding and controlling a chemical chain reaction capable of multiplying the radiation effect on a single molecule. The special requirements are that the nuclear radiation initiate a minimum chain length approximately $10^5$ for visual perception and that it not be initiated significantly by thermal radiation at ordinary temperatures. Five possible ways in which multiplication may be achieved are:

A. Development reaction such as photographic development.

B. Explosive reactions such as benzoyl peroxide triggered by nuclear radiation.

C. Initiation of a free radical chain.

D. Psychological, such as a color reaction.

E. Thermoluminescence.

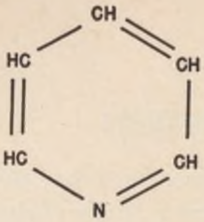
A few examples of many proposed systems for accomplishing the above multiplication are indicated below.

*Phosphors*. The development of a dosage indicating device in which a phosphor screen is combined with a photo-sensitive layer. The phosphor absorbs the high energy photons to which the photo-chemical layer is nearly transparent with the phosphor emitting an extremely large number of photons of ultra-violet light for each high energy photon absorbed. The photochemical layer absorbs the ultra-violet emission and in turn may be direct reading in shades of grey or in colors after a development process. This is an effective way to transform high energy radiation into a detectable form.

*Colored Dyes*. The formation of colored dyes on exposure to radiation of luecocyanides with pararosaniline.

*Halogenated Compounds*. The radiation decomposition of halogenated compounds can be used to produce color reactions.

*Pyridine Ring*. The splitting and coupling of the pyridine ring under the influence of ionizing radiation may form colored compounds.



*Decomposition of Carbon Tetrachloride.* Carbon tetrachloride ($CCl_4$) in the presence of water and oxygen decomposes under radiation into chlorine ($Cl_2$), carbonyl chloride ($COCl_2$), and hydrochloric acid (HCl). The chlorine can be detected by the starch iodide reaction or by more sensitive and stable indicators such as thio-Michler's ketone. Other chlorinated compounds such as DDT, chloro- and hexachloroethane react in a manner similar to carbon tetrachloride.

*Reduction of Mercuric to Mercurous Salts.* Mercuric chloride ($HgCl_2$) or iodide ($HgI_2$) is reduced to mercurous (HgCl or HgI) and probably to metallic mercury by radiation. An early equilibrium is reached between the reduction products and the original salts, however, the reaction can be made to go forward by having present an acceptor of oxygen. Such an acceptor is tetramethyl diamino diphenylmethane which is oxidized to a deep blue diphenylmethane dye. A mixture of mercuric ($Hg^{++}$) chloride and thio-compound therefore undergoes a change from colorless to blue upon irradiation. There is a possibility that the mercurous salt ($Hg^{+}$) or the fine mercury formed in this reaction can be utilized to catalyze some chemical reaction which would result in greater sensitivity.

*Reduction of Cupric to Cuprous Salts.* Cupric chloride ($CuCl_2$) or bromide ($CuBr_2$) is reduced to the corresponding cuprous salts ($Cu_2Cl_2$ or $Cu_2Br_2$) on irradiation. It has been found that thio-Michler's ketone can be used as a sensitive indicator for this reaction since it forms deeply colored complexes with cuprous ($Cu^{+}$) but not with cupric ($Cu^{++}$) salts.

*Reduction of Molybdic Acid.* Molybdic acid ($H_2MoO_4$) is reduced slowly to a blue compound, molybdic blue ($Mo_2O_5.nMoO_3$) on irradiation. Much greater sensitivity is obtained if an organic acid such as lactic acid is present.

*Reduction of Nitrates.* Nitrates ($NO_3^-$) are reduced to nitrites ($NO_2^-$) by radiation. The nitrite can be detected by the formation of azo dies.

### 9.03 Scintillation Counters

Crystals such as Napthalene ($C_{10}H_8$), anthracene ($C_6H_4{:}(CH)_2{:}C_6H_4$), calcium tungstate $CaWO_4$), silver chloride (AgCl), thallium-activated sodium iodide (NaI), thallium-activated potassium iodide (KI), and others have been found to have a relatively high fluorescent yield. These crystals, in conjunction with light sensitive devices such as high-gain photomultiplier tubes are in use as research tools, but as yet no successful survey instruments have been delivered; however, development of such equipment is in advanced stages. It is felt that the *scintillation* type counter can be utilized to overcome many of the serious problems of high resistance, insulation, and thin windows associated with alpha counting by ionization chambers and proportional counters. In addition, it is felt that scintillation counters may provide a wide range instrument to replace the use of Geiger-Mueller counters for low intensity gamma detection and ionization chambers for high dose rate gamma survey.

Some problems are encountered with the scintillation counter. There is a spectral sensitivity problem such as that discussed in conjunc-

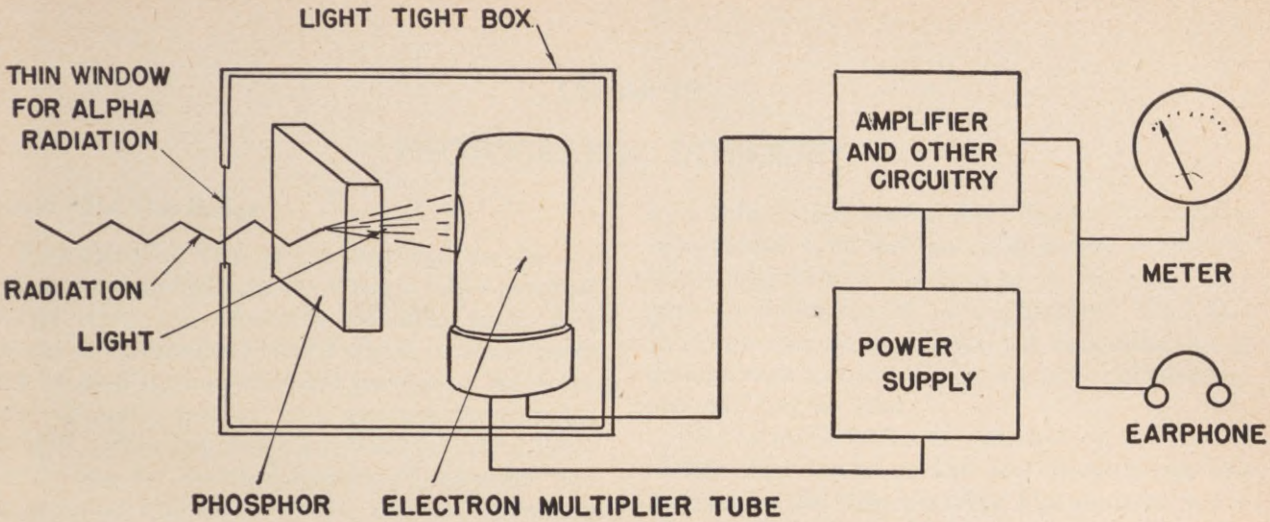



*Figure 31. Schematic diagram of a scintillation counter.*

Radiation striking the phosphor releases light which is picked up in the electron multiplier tube and is subsequently transformed into a meter reading or earphone indication.

tion with ionization chambers. Satisfactory photoelectric tubes require in the neighborhood of 100 volts per stage and with 10 or more stages this presents the same high voltage problem discussed in conjunction with Geiger-Mueller counters. Since the photomultiplier tubes are light-sensitive, the tube and crystal must be encased in a light-tight coating.

## 9.04 Other Possibilities

Several other processes have been examined for their possible use as dosage-indicating devices. Electrets show some promise, but further investigation is necessary before their actual application to dosimetry may be used as a basis for long-range planning.

## Chapter 10

# PHOTOGRAPHIC DOSIMETRY

### 10.01 The Film Badge

Photographic films are in universal use for the measurement of gamma ray dosage. As a personal badge, they are especially valuable since they produce a permanent record which in many cases can be used for medical-legal purposes. As in the case of light, gamma rays produce developable images. Photographic materials find many laboratory uses for the measurement of radiation, and as such may find their way into the field laboratory (6). For the present, however, we will consider only dosimetric applications.

A film badge as shown in figure 32 usually consists of a packet containing one or more photographic films of dental size (1½ inches by 1¾ inches) wrapped in a thin material which is opaque. The whole unit may be sealed in a waterproof paper or cloth envelope. The sensitive emulsion consists of a thin layer of a silver halide and gelatin spread on a cellulose film base. The interaction of radiation with the silver halide is understood to be some type of ionization which produces a developable latent image. The developing process converts the latent image into a deposit of black silver metal. Some sections of the film packet may be covered by a thin (1 mm) lead shield* designed to exclude beta particles, so that an examination of the film blackening behind the lead or in the clear may give an indication of beta exposure. The lead shield also serves to enhance the darkening due to gamma rays because of a large number of electrons ejected from the lead.

Placing an identification number on the outside of the film badge packet and transferring this number to the light sensitive film presents somewhat of a problem. If this is done manually, the time involved, except for minor numbers of badges, becomes prohibitive. Some investigations are being made into the possibility of using X-rays to expose a number punched out of a thin metallic sheet which would be incorporated into a section of the covering envelope. Today there is nothing which can be considered as a satisfactory identification system for military usage.

### 10.02 The Densitometer

A densitometer is used to measure the blackening of the film, and this is compared to the blackening of standard calibrated samples. The sche-

* Cadmium has had some use in film badge shields.

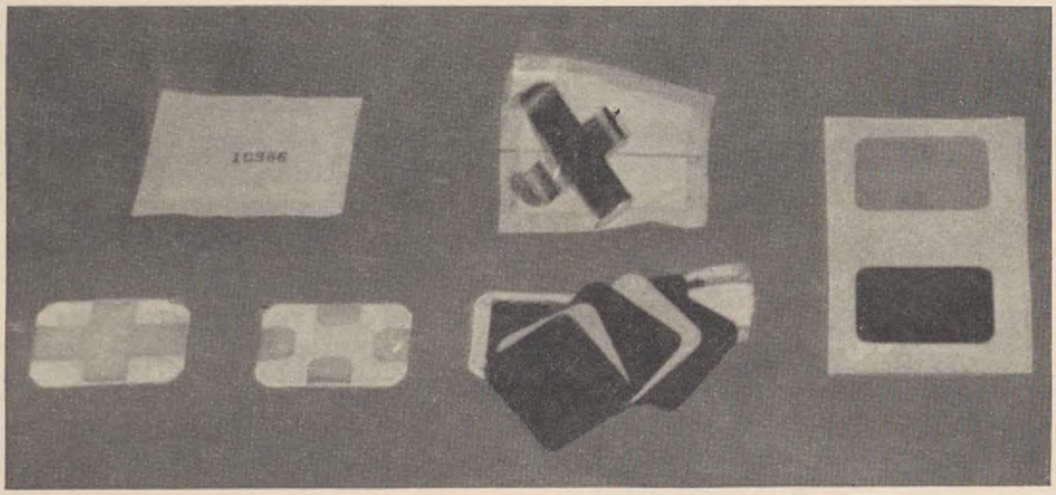


*Figure 32. Film badge.*

Top left is the badge with serial number on waterproof cover. Below are front and back views of packet with lead cross. Top center is an opened cover and lead cross; bottom, badge opened to show paper dividers and films. At right are two processed films.

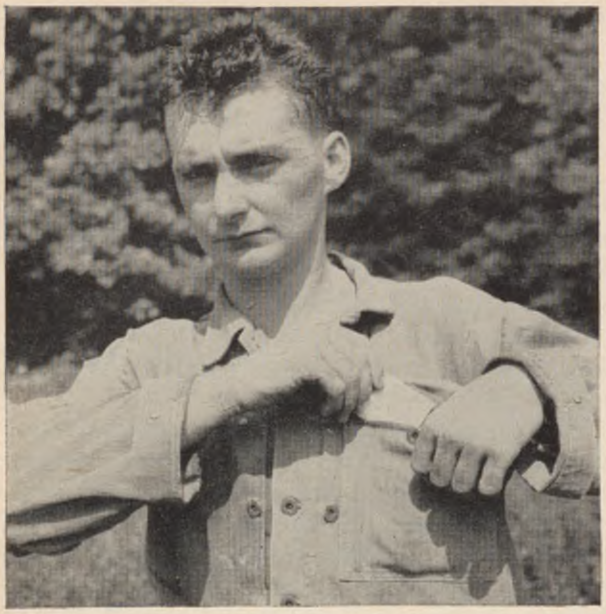


*Figure 33. Film badge carried in shirt pocket.*

matic arrangement of a densitometer is shown in figure 34 and a densitometer in use is shown in figure 35.

The image of a small area of the film is allowed to fall upon a photocell which in turn is connected to a microammeter. Light falling directly upon the photocell will produce a reading, $I_o$. When the film is put in the light path, some absorption will take place, and a lower reading, I, will result. The ratio $\frac{I_o}{I}$ is called the opacity, O. The transparency, T, is the reciprocal of the opacity or $\frac{I}{I_o}$. The optical density, D, of the silver deposit on the photographic film is defined by the relation:

$$D = \log_{10} O = \log_{10} \frac{I_o}{I}$$

In figure 36 the density is plotted against the log of relative exposure, and the *characteristic curve* of a film emulsion is obtained.

## 10.03 Film Processing

The characteristic curve will start with some minor density at A which the cellulose acetate backing contributes. Some exposure is required to overcome the inertia of the film in the toe portion A–B. The shoulder portion C–D shows that at some point continued exposure fails to make very much of a contribution to increasing the density. For the greatest accuracy only the linear portion of the curve B–C should be used, since the greatest change in density occurs with change in exposure. There is a limited range of sensitivity for any one emulsion; therefore, several emulsions may be combined into one film badge packet, to give an extended range (see sec. 15.08 on page 81).

Variations in film processing can introduce possibilities of serious errors. The film density is a function of time and temperature of development, developer solution strength, and the degree of agitation in the developer. Every effort should be made to follow a standard processing procedure such as that recommended by the film manufacturer. As a very rough rule of thumb, it can be stated that a one-degree change in developer temperature can introduce a three to six percent variation in the roentgen reading, and a sixty-second time variation may introduce five to ten percent variation. There are circumstances when these variations can be much greater. Film processing is therefore very critical and must be controlled carefully. Under the majority of field conditions it will be extremely difficult to maintain the required controls, and until automatic high speed developing and densitometric reading equip-

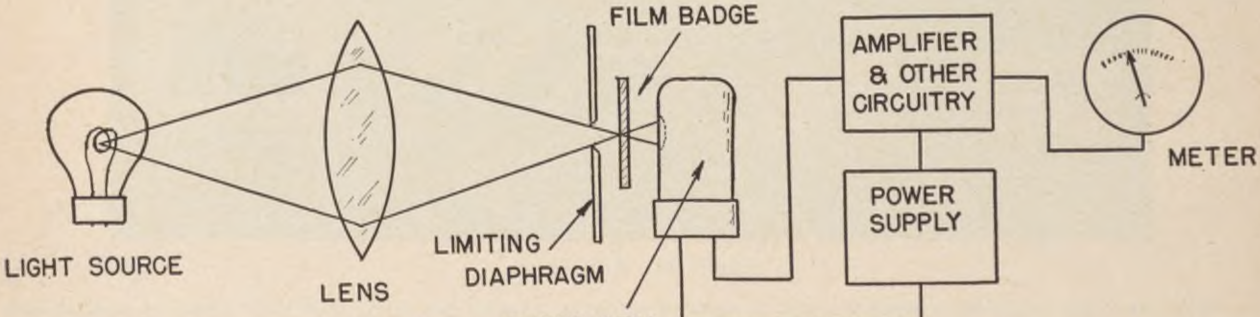



*Figure 34. Schematic arrangement of a densitometer used to determine film badge readings.*

*Figure 35. Densitometer in use.*

The density of each individual film badge must be obtained and compared against the density of similar films calibrated against known radiation sources in order to determine dosage readings.

ment is put into use, the volume of film badges that can be processed is limited seriously. From the start of development to the completion of densitometric measurement using standard techniques, a time of roughly one hour is required for one film.

It is found that no two batches of the same film from the same manufacturer have exactly the same response to radiation. This can introduce serious difficulties if ignored and requires that a calibration be made for each batch. As in the case of other photographic materials film badges have a limited shelf life even under the best storage conditions. There are also gradual changes in the film characteristics with time which requires that continuous calibration checks be made. The method of calibration will be discussed in chapter 13.

Although there are objections to film badges, they are a very important dosage recording device.

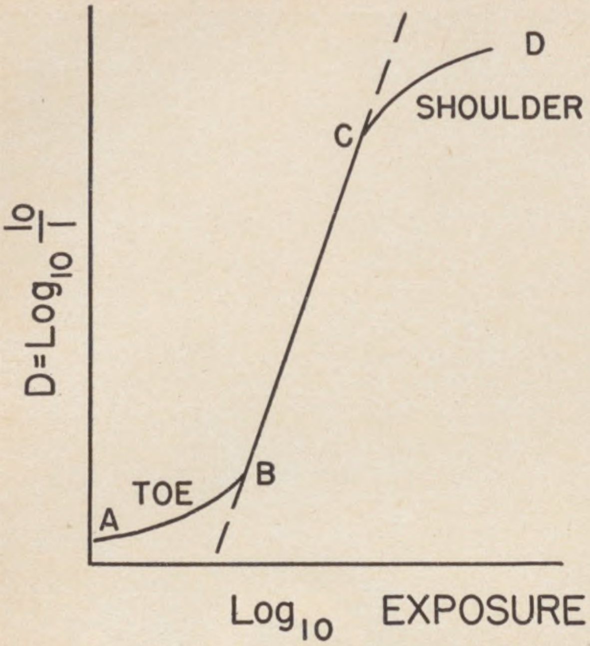



*Figure 36. Characteristic curve of a film badge emulsion.*

The size, weight, record permanence, simplicity, and cost when compared with the various disadvantages, may outweigh the use of more complicated electronic devices which require considerable upkeep and adjustment. It is certain that film badges will be used for health protection of any military participation in future atomic weapon tests. Radiation exposure has become one of the standard entries in military health records (see fig. 37) and film badges, because of their permanence, are filed to substantiate any such entries.

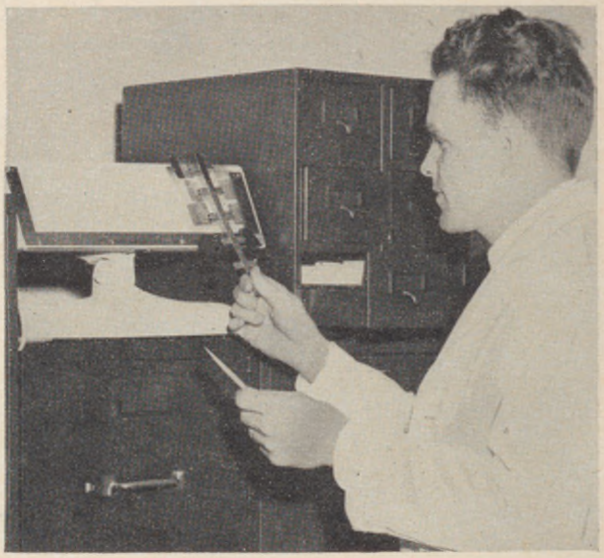


*Figure 37. Medical records.*

Radiation exposure has become a standard entry in military health records; and film badges, because of their permanence, are filed to substantiate any entries.

## Chapter 11

# CLOUD CHAMBERS AND ACCELERATORS

The *cloud chamber* is one of the most useful tools for the scientific examination of the properties of the atomic nucleus and of the various particles and radiations. Such an instrument has no foreseeable military applications; however, the cloud chamber is advertised widely, and a brief statement is considered essential to give a well-rounded description of radiac instruments.

Ions caused by a charged particle may act as a nucleus for condensation in a supersaturated vapor. Radiation passing through such a vapor will produce ions which will cause droplets of vapor to form that may be seen by the naked eye or photographed by a camera under certain conditions. When such cloud chambers are used in conjunction with magnetic fields, the curvature and extent of the vapor trails can be utilized to give indications of charge, velocity, mass, etc., of the initiating radiation.

Another group of machines called *accelerators* are used as tools of the physicist in his examination of the structure of matter. Descriptions of the linear accelerators, van de Graaf generator, cyclotron, synchrocyclotron, betatron, synchrotron, Bevatron, etc., may be found in most modern physics texts (2) (7). They have no application to the problems of military radiological defense. It should be noted that a number of the radiac instruments herein described were developed for the health protection of personnel employed in the vicinity of high energy accelerators.

# Chapter 12

# SHAPE AND CHARACTERISTICS

## 12.01 Introduction

No attempt will be made in this article to dictate military characteristics for the various radiac instruments and equipments, but a slight indication of the degree of evolution is considered of some value to personnel who are unfamiliar with the field.

The portable instruments now available to the military are, in most instances, laboratory equipments which have been altered to hand carrying cases. They have undergone enough development so that they can render satisfactory military service as training instruments and, in the event of emergency, would no doubt give good service within the continental limits of the United States.

It is doubtful, because of the peculiarity of construction and lack of standardization of certain components, such as high resistance resistors, Geiger tubes, electrometer tubes, and the like, whether these interim instruments would be entirely suitable in oversea military operations. Such instruments have not yet reached a point of service acceptability by either field or landing forces. It is anticipated that the development programs now under way will produce satisfactory equipment within the next 12 to 18 months. It is certain that if the necessity arose tomorrow, the interim instruments could be used to advantage.

## 12.02 Physical Characteristics

The great majority of the portable radiac instruments of the types in which we are interested are housed in rectangular metal cases of roughly 250 to 500 cubic inches. Carrying has been by means of a handle on the top of the instrument and by a carrying strap attached to eyes on the ends of the instrument case. The instrument weights run between 7 and 15 pounds.

Field tests during atomic weapon test explosions (8) have given us some criteria for the design of hand-carried instruments. There are virtually no indications as to proper form factor for instruments carried by pack, attached to the belt, etc. So far only one attempt has been made to deviate from the ordinary shoulder strap and handle type instrument. This deviation is the AN/PDR–8 Geiger counter which is built to fit over the stomach, with the carrying strap running around the back of the neck. Several tests indicate that this method of carrying the instrument may have some slight advantage in going through hatches and up and down shipboard ladders. For any other type of use, it is found that the neck rapidly tires, making the neck strap less satisfactory than a strap which crosses the body over one shoulder. Also, the stomach-carried instrument does not lend itself to ease in being hand-carried.

As in the case of everything else that one may be required to transport, the ultimate goal is zero weight and zero size; however, this not being practical, there are some immediate goals which may be set. It has been found that a rectangular shape, roughly eight inches long, five inches wide, and six inches high, weighing not over eight pounds, can be carried by hand or by shoulder strap for extended periods of time. In any operation where instruments must be handed from person to person, such as from ship to small boat, or in and out of vehicles, etc., a rigid handle has been found more desirable than the hinged suitcase type. It should be obvious that a broad shoulder strap is desirable for comfort in instrument carrying, although some instruments come equipped with straps only slightly wider than a shoe string.

One of the most important considerations is the location of the instrument's center of gravity. Too many instruments have a tendency to fall on their sides when carried on the seat of a jeep or placed on the deck of a boat. Experiments indicate that the minimum angle from the vertical to which the instrument can be tilted prior to falling over is 35 degrees.

Disposable transparent plastic covers have been used to prevent instrument contamination. In many cases these covers were more of a nuisance than they were worth. The majority of instru-

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ments now have smooth hard finishes from which contamination may be washed. Future designs should consider the elimination of any unnecessary protuberances, such as meter housings, which would be contamination collectors.

Many of the high range instruments will be used by personnel wearing gloves, and this fact has been overlooked in the placing of knobs and switches on a great number of instruments. There is also the possibility that some of the instruments will be used by personnel wearing gas masks and, therefore, meter markings should be such as to present no opportunity for misreading. Scale numbers which change with a change in the range scale, along with distinguishing colors, are certainly recommended. Also, a means for illuminating the scale for night operation is recommended.

Military radiac equipments will, in all probability, have changeable scale markings with changes in scale ranges. In addition, the scales will have distinguishing colors. For gamma rate meters, the following range scale colors have been accepted:

| | |
|---|---|
| 0—500 r/hr | fire engine red |
| 0—50 r/hr | light magenta |
| 0—5 r/hr | orange |
| 0—500 mr/hr | yellow |
| 0—50 mr/hr | white |
| 0—5 mr/hr | green-yellow |
| 0—0.5 mr/hr | light blue |

It is anticipated that a color patch scheme will be standardized for dosage recording instruments, film badges, etc., which will match that of the rate meters somewhat as follows:

| | |
|---|---|
| 500 r or higher | fire engine red |
| 50 r—499 r | light magenta |
| 5 r—49 r | orange |
| 500 mr—4.9 r | yellow |
| 50 mr—499 mr | white |

An experienced field soldier, on examination of the better commercial Geiger-Mueller detectors, may be appalled at the bright chromium-plated

*Figure 38. Existing equipment tried during field problems is found to be lacking in many characteristics.*

tube probe; or a marine may complain that it would be impossible to drag any of the ionization chamber instruments along when involved in jungle fighting. Others, depending on their missions, will find faults with any of the present equipments. This is the state of development. To date, the greatest emphasis has been placed on obtaining proper instrument response with the idea that once this has been achieved, some of the other characteristics will receive attention.

## 12.03 Electrical Characteristics

Characteristics will, of course, vary from instrument to instrument and will depend somewhat upon the use for which the instrument is intended. Some of the more important characteristics which are somewhat unique to radiac instruments will be indicated.

A. Ability to Zero in Field

The electronic circuit should be so designed that it will zero automatically on high dose rate of the instrument under background radiation intensities less than 0.05 mr/hr.

B. Metering Time Constant

Depending on the purpose for which the instrument is used, after an initial warm-up period the time constant should be such that 95 percent of the final reading is reached after a maximum period of one second. For low intensity ranges such as 5 mr/hr this time constant may be longer.

C. Pressure and Temperature Effects

The majority of commercial instruments having non-military standard batteries may be subject to many temperature problems. Most organic quenched Geiger tubes will cease to function a few degrees below zero Fahrenheit. Ion chamber instruments are subject to many difficulties with changes in pressure due to use or transport by air. Military gamma measuring chambers require constant reading over a change in elevation from sea level to 36,000 feet. Efforts are being directed toward covering the temperature range of —40 to +125° F.

D. Saturation Effects

To prevent an erroneous assumption as to the absence of radiation, the instruments should show no effects of saturation of the detector component until radiation intensities of at least five times the maximum reading of the instrument are encountered.

## 12.04 Radiological Characteristics

On page 12 an indication is given of the spectral sensitivity problem. It is felt that gamma response in roentgens should be held within $\pm 20$ percent of air equivalent over the range 80 Kev to 5 Mev. At the same time, the instrumental inaccuracy should not be more than $\pm 10$ percent of the scale reading for any point above 10 percent of the scale for energies between 1 Mev and 3 Mev.

For beta survey purposes, wall thickness of 30 mg/cm$^2$ are recommended. Thinner windows of the order of 3–4 mg/cm$^2$ will be required for beta admission during certain decontamination processes.

Instruments for alpha detection must record particles having a minimum range of 3 centimeters.

# Chapter 13

## CALIBRATION

A problem which at first appears of little consequence is that of instrument calibration. Actually, this is an extremely serious problem to designers, manufacturers, and to users whether in laboratory or field work. There are two calibrations which must be considered:

a. Spectral sensitivity, and

b. Dosage rate.

The first is a function of the materials, configuration, etc., of which the instrument is made. Military radiac equipment is checked for spectral response by the X-ray section of the National Bureau of Standards, and it is considered that they are not likely to change unless the instruments are damaged or altered. Unfortunately, the instrument evolution has not progressed to the point where one is willing to use them per se without continuous rate calibrations.

If errors, some serious, are to be eliminated from quantitative dose rate measurements, then it is necessary to expose the instruments in substantially the same manner in which they are calibrated. This does not mean that qualitative indications cannot be obtained when an instrument is not calibrated for a specific radiation. In the case of the portable Geiger-Mueller counter the instrument is calibrated for gamma radiation but is satisfactorily used to locate beta surface contamination. An extremely complex beta calibration with rigid use restrictions would be required to make the Geiger-Mueller counting rate a quantitative measure of active material.

Alpha calibrations are done with plutonium or uranium sources at the center of the plane of the external opening of the instrument. As a matter of interest, it can be stated that one gram of pure natural uranium emits a total of $2.5 \times 10^4$ alpha particles per second. Considerable effort must be placed in determining the absolute number of disintegrations for any sample to correct for self-absorption and geometry.

Beta calibrations present a more serious problem than do alpha, primarily because of scattering effects and absorption of the beta particles. A good number of standards are made by depositing on a foil a known amount of uranium oxide ($U_3O_8$). The foil having a density of 25 mg/cm$^2$ will absorb all alpha particles and only about five percent of the beta particles. Strontium 90 is also used as a beta calibration source. It should be noted that the methods of alpha and beta calibrations are not entirely satisfactory and that work is under way to develop better means of calibration.

Radium encased in platinum and cobalt 60 are used as gamma radiation sources for calibration. Sources are calibrated at the National Bureau of Standards at periodic intervals. Information from the source calibrations allows a calculation of intensity at one centimeter from the source. Intensities at other distances are found by use of the inverse square law.

In the case of radium, the following relationship exists:

$$I_{Ra} = \frac{8.4m}{d^2}$$

where $I$ is the dose rate in roentgens per hour at a distance $d$ centimeters from a source of mass $m$ milligrams. The half life* of radium being relatively long (1,600 years), there is little worry about changes in source weight over periods of months. Cobalt 60, on the other hand, has a half life of 5.3 years, and it is therefore necessary to include the elapsed time $t$ in days from the date of source calibration. The radioactive cobalt is produced artifically in a rod of ordinary cobalt metal through neutron irradiation in an atomic pile. A number of atoms within the rod will not become radioactive; therefore, the weight of the sample is not necessarily indicative of the radioactivity. As a result, the source activity A in millicuries** giving a numerical quantity of dis-

*The half life of a radioisotope is the time required to lose half of its activity.

**Millicurie = 1/1000 curie. The curie is generally accepted as that quantity of substance which decays at the rate of $3.7 \times 10^{10}$ disintegrations per second. The millicurie (mc) has a disintegration rate of $3.7 \times 10^7$ disintegrations per second.

*Figure 39. Gamma calibration.*

Three ionization chamber survey meters are calibrated against a cobalt 60 source.

integrations per second at the time $t$ must be given. The calibration relationships for $Co^{60}$ are:

$$I_{Co^{60}} = \frac{8.4A \cdot e^{-\frac{0.693 \times t}{5.3 \times 365}}}{d^2} = \frac{8.4A \cdot e^{-3.58 \times 10^{-4} t}}{d^2}$$

An open area usually is marked off into concentric circles with the source of radiation placed at the center as shown in figure 39. Such an arrangement can be used for the rapid calibration of large numbers of medium level dose rate instruments. Instruments calibrated at extremely high levels, such as 100 to 500 roentgens per hour, require remote control devices to move the instrument and make adjustments in order to minimize personnel exposure.

It should be noted that geometrical considerations limit the maximum intensity which can be obtained from a single source. This closest approach of the instrument to the source at which it can be considered that the square law still holds and at which the detector is receiving a uniform radiation may be taken as equal to 10 times the maximum dimension of the detector.

The gamma calibration of film badges, dosimeters, and other dosage reading is accomplished in a manner similar to that explained above for intensity meters except that the time of exposure at a given intensity must be measured carefully.

## Chapter 14

# OPERATIONAL INSTRUMENTATION

### 14.01 Available Instruments

The various instruments and techniques for radiation measurement have been covered in a rather complete but general way. As far as operations are concerned, with the exception of the field laboratory, the following are the instrument types which are available for military use:

1. Geiger-Mueller counters—
   Low level beta-gamma detectors for—
   - a. Field detection.
   - b. Warning.
   - c. Decontamination detection.
2. Ionization chambers—
   High dose rate gamma survey—
   - a. Ground.
   - b. Ground from the air.

   Direct and indirect reading personnel dosage recorders.

   Group dosage recorder.

   Alpha detectors in low beta-gamma background.
3. Proportional counters—
   Alpha detection and survey in medium beta-gamma background.

   Decontamination detection.
4. Photographic film badges—
   Gamma dosage recorder.

   Indicator of beta exposure.

   Track plates for laboratory alpha measurements.

A tabulation of use, state of development, etc., for various instruments is given in table III.

In radiological warfare, whether it be atomic bombs or a radioactive agent, the chief radiations are the alpha and beta particles and the gamma rays. In the case of a high altitude bomb blast virtually all radioactivity is contained in the resulting cloud. Some of this material may fall out on the earth's surface many miles from the blast, but in general the radioactivity of the fall-out will be low intensity alpha, beta, and gamma. As the explosion occurs closer to the ground, neutrons produced during fission may induce beta and gamma activity into the ground materials which absorb them. Also, as the explosion occurs closer to the ground, there will be certain quantities of unused fissionable alpha producers and beta-gamma emitting fission products which will be deposited on the ground. Alpha, beta, and gamma emitters are possible radiological agents, although they will more probably be either beta or gamma or a combination of beta and gamma (see page 3).

In the case of an under-water bomb explosion, beta-gamma active fission products and unfissioned alpha-emitting bomb materials will be held, to a large degree, in a cloud which spreads out and rains down on the surrounding landscape. Certain beta-gamma activity will be produced through the neutron irradiation of water contaminants such as the salt in sea water. The contaminated cloud may contain radiating materials which will give lethal doses with exposures of a fraction of a minute. This cloud material in settling onto the surface of the earth may deposit contamination which will produce gamma dosage rates of several hundred roentgens per hour.

Atomic bomb explosions in contact with the ground or underground will result in contamination somewhat different from that occurring with the one under-water shot which has been fired. Beta-gamma active fission products and unfissioned alpha emitting bomb materials may be held in a large cloud of dust and earth particles which may spread out and settle on the surrounding landscape. In the immediate vicinity of the point of detonation will be a crater depending in size on many different variables such as density and type of soil, strength of bomb, depth of explosion, etc. The crater, in addition to the high activity resulting from the various bomb contaminants, will have neutron-induced activity and shortly after the blast may have gamma dosage rates of many hundreds of roentgens per hour.

TABLE III.—*Use of various radiac instruments*

| Instrument | Purpose | Radiation | | | Use | Remarks |
|---|---|---|---|---|---|---|
| | | Alpha | Beta | Gamma | | |
| Pocket dosimeter | Individual exposure | ------ | ------ | X | Field or laboratory | High cost compared to pocket chamber. Requires separate charger. |
| Drift meter | Rate of exposure | X | X | X | Secondary standard in conjunction with laboratory. | |
| Pocket chamber | Individual exposure | ------ | ------ | X | Field or laboratory | Requires a separate charger-reader. |
| Thin window chamber | Rate of exposure | X | X | X | In conjunction with laboratory. | Many problems involved with thin windows. |
| Chamber survey | Rate of exposure | ------ | ------ | X | Field or laboratory | Use for high dose rate radiation measurement. |
| Proportional counter | Disintegration rate | X | ------ | ------ | In conjunction with laboratory. | Many problems involved with thin windows. |
| Geiger counter | Rate of exposure | ------ | X | X | Field or laboratory | Limited to detection and low dose rate. |
| Scaling circuit | Cumulative record | X | X | X | Laboratory | |
| Count rate meter | Rate of exposure | X | X | X | Laboratory | |
| Scintillation counter | Rate of exposure | X | X | X | | |
| Film badge | Individual exposure | ------ | X | X | Field or laboratory | Teriffic problems involved with development in any quantity. Gives a permanent record. |
| Track plates | Degree of contamination | X | ------ | ------ | Laboratory | |
| Color crystals and liquids, chemicals, photo conductive crystals, etc. | Individual exposure | ------ | ------ | X | | |
| Electrets | Individual exposure | X | X | X | | |

One of the reasons for the high beta-gamma activity immediately following an atomic bomb explosion is the short half-life elements either produced as fission products or as the result of neutron irradiation. This high activity results in the rapid decay and rapid removal of the beta-gamma hazard. In the case of an air burst, depending on height and many other variables, the area beneath the blast may be safe from an emergency military beta-gamma standpoint, within less than an hour after the burst. This is not the case if alpha emitters remain after a bomb explosion. These will not show high initial activity and will not decay immediately to a point of no concern but may remain for years to plague occupants of a contaminated area. Being alpha and not active in enormous quantities, they may be overlooked because of the difficulty of detection, and perhaps through their introduction into foods, water, ventilating systems, etc., may present a definite hazard to a long term military organization.

To give indications of possible military usage, instruments will be discussed in conjunction with each type of radiation.

## 14.02 The Alpha Particle

Because of the very short range and penetrating power, alpha particles are very difficult to measure. A 5 Mev alpha particle has a range of only 3.5 centimeters in air; therefore, the maximum distance a detector with an air window can be

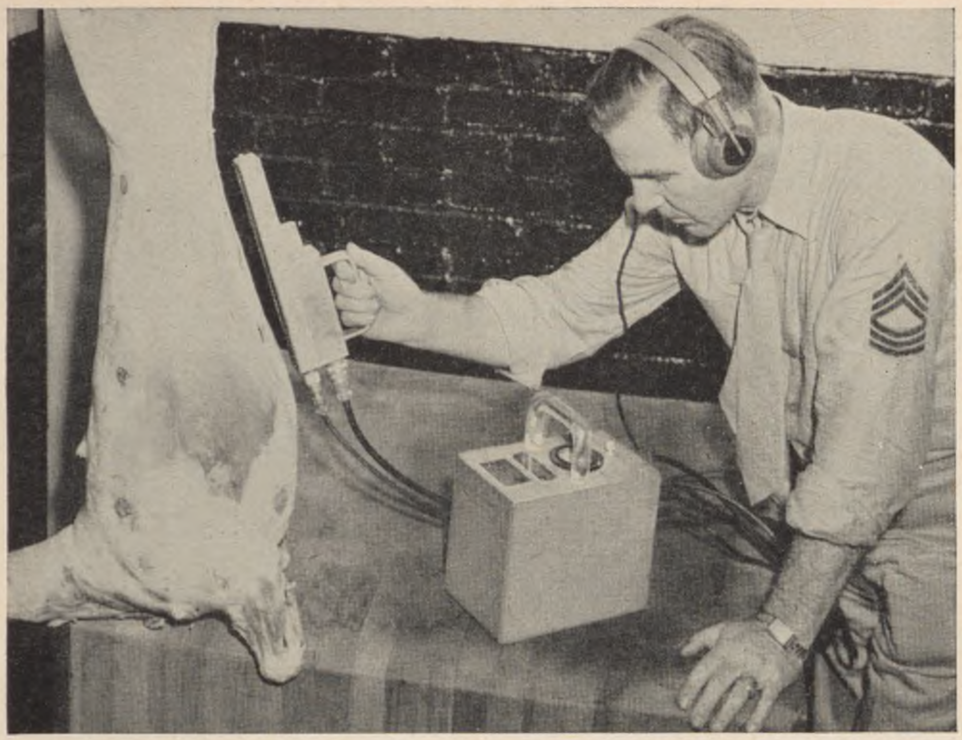

*Figure 40. Checking meat for alpha contamination with a poppy-type portable proportional counter.*

from such a particle is 3.5 centimeters. A closer distance is required, since not all particles will travel at right angles to the emitting surface. Partial shielding by the emitting surface will also reduce the travel distance as will lower particle energies.

Detailed alpha measurements will be made in conjunction with decontamination work and will be specified in alpha disintegrations per unit of time per unit of surface area.

It is difficult to establish general rules for all types of alpha emitters. Their hazard is internal from inhalation and ingestion, and different elements are deposited in different organs and as a result will produce varying degrees of damage (9). As a crude attempt to establish over-all working values for field use, the following are given: (a) food not to exceed one meal—a maximum level of 300 disintegrations per minute per square centimeter of surface; (b) air containing uniform dust contamination measured at any surface to have a level of not more than three disintegrations per minute per square centimeter for a maximum exposure of eight hours; and (c) drinking water, when activity is measured on an open surface, not to exceed 1,000 disintegrations per minute per square centimeter for no more than a one-day supply. It must be remembered that the effects of alpha activity, whether from food, drink, or breathing, are cumulative.

An ionization chamber such as Radiac Set AN/PDR–20 will measure the total ionization produced in the chamber and not the number of disintegrations. However, a rough calibration in terms of number of disintegrations can be made so that the instrument is not completely useless. It must be remembered that beta and gamma activity will contribute to the reading, although their contribution can be estimated by the use of an alpha absorbing shield in front of the window.

Portable proportional counters (fig. 40) such as Radiac Set AN/PDR–10 with a large probe window will be the primary alpha detectors. These instruments will be adjusted to respond only to highly ionizing events and will be useful except in cases where the beta-gamma to alpha ratio exceeds $10^7$. The instrument is capable of high counting rates. Operation is limited to relatively dry weather, since high voltage leakage in the chamber will result in spurious counts.

Neither Geiger-Mueller counters nor film badges will be used for alpha detection in military operations.

Alpha counting must be performed by well-trained monitors working in conjunction with the field laboratories in which a large portion of the determination of alpha hazard will be made. For example, none of the instruments we have just discussed are satisfactory for measuring alpha activity in drinking water or in air. A photographic process involving nuclear track plates may be used in some laboratory alpha investigations (6).

### 14.03 The Beta Particle

Faulty measurement of beta particles probably presents the greatest hazard of any radiations to be encountered in military operations. Very low energy (soft) beta particles present virtually the same measuring problems as do alpha particles. As a result, the soft beta particles, which are dangerous if inhaled or ingested, may be ignored. High energy (hard) beta particles, on the other hand, may penetrate gamma shields and give what appears to be enormously high gamma readings.

Beta measurements may be made both in conjunction with decontamination and area survey. Beta particles and gamma rays will always be found in some ratio. For example, immediately following a bomb blast the ratio will be much higher than, say, one month later. Beta particles, because of their low penetrating power, are as a general rule considered as only an ingestion or inhalation hazard. As in the case of alpha emitters, the various elements will lodge in different internal organs; therefore, the beta tolerance levels are primarily a function of the emitting element. Detailed determination of the specific elements and beta-gamma ratios will be a function of the field laboratory. In many cases, field laboratory information will allow a monitor to determine beta hazard through gamma measurements.

Specific information is lacking on the tolerance range which will be referred to in military operations. Ionization chamber instruments such as the AN/PDR–20 with thin windows and the AN/PDR–8 (series), 27, and T–2 Geiger counters can be used to indicate beta particles. Both the ionization chamber and the Geiger-Mueller counter (fig. 41) will read the combined beta plus gamma activity. However, it is possible to estimate the gamma contribution by placing a beta absorbing shield over the chamber or tube window. In the case of the Geiger-Mueller counters AN/PDR–T–2 and AN/PDR–7, having thin wall tube sections around 30 mg/cm$^2$, beta particles of energy less than 160 Kev will be excluded. The very thin 3–4 mg/cm$^2$ windows associated with Radiac Sets AN/PDR–8 (series), and AN/PDR–27 will cut out soft beta activity below 50 Kev.

Beta measurements with thin wall Geiger-Mueller tubes in instruments calibrated in roentgens (the roentgen will be discussed under gamma ray measurements) may cause some trouble, since there is no relationship between the roentgen (a measure of electromagnetic radiation) and quantities of beta particles. With the probe shield open and the tube directly exposed to beta radiation, the instrument will in general read several times the gamma ray reading with the shield closed. (See discussion on page 55.) This feature adds to the sensitivity of the equipment when used as a detector for decontamination. It must be emphasized that the beta particle reading bears no relation to the roentgen and cannot be converted into these units. Only for beta particles of one specific energy can a certain roentgen rate reading be stated as equivalent to a certain number of disintegrations per second. This will not be true for beta particles of other energies. This entire problem has led to the recommendation that beta-gamma sensitive Geiger counters have an inscription on the dial: mr/hr—hard gamma only.

Proportional counters find little use in beta measurements, particularly since any counter sensitive to hard beta will be sensitive to gamma rays, and the selective advantage of the proportional counter is lost.

As previously indicated, personnel film badges utilize a lead shield over a portion of the film so that the unshielded section of the badge may give a beta plus gamma reading and the shielded portion a gamma reading only. The beta exposure determined by this method cannot be considered too satisfactory since the waterproof envelope and light-tight paper container, plus the cloth and other substances in the wearer's pocket, will give an unknown degree of beta shielding. If photographic film badges are to be used to any extent for the measurement of external beta exposure

*Figure 41. Geiger counter in use with beta shield open to increase detection sensitivity in checking for ground contamination.*

during military operations, it will be necessary to prescribe exact methods of attaching the badge to the person. This in itself is not a complete solution, since body shielding, equipment, etc. may give degrees of shielding which will give false results.

## 14.04 The Gamma Ray

Because of its range and great penetrating ability, the gamma ray presents the least difficulty of measurement. As stated previously, it is fortunate that the greatest military preoccupation will be with gamma rays. This of course, means that the greatest emphasis must be placed on accurate gamma-measuring instruments.

The unit of photon absorption, called the *roentgen,* is universally used for measurement of gamma ray dosage. In terms of this unit we state that the permissible amount of gamma radiation to which the body may be exposed for routine, every-day peace time operations is 0.1 roentgen (r) or 100 milliroentgen (mr) per day. This is in the process of being revised downward to a total of 300 mr per week. For the purpose of performing some especially important mission in conjunction with field tests of atomic weapons, a maximum single

exposure of 3 r is prescribed, provided no further exposure is allowed over a period of 30 days. In the event of atomic attack, exposures up to 75 r (perhaps 100 r) will be permitted as one of the normal hazards of war. Exposures of 75 r or greater are of considerable interest to commanders for the further employment of personnel and to medical officers for proper treatment of casualties.

In 1928 an international committee for radiological units defined the roentgen as the quantity of x or gamma radiation such that the associated corpuscular emission over 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign. It turns out that one cubic centimeter of dry air under standard conditions of temperature and pressure weighs 0.001293 gram, and that $2.083 \times 10^9$ ions of either sign are required to produce one electrostatic unit. Further examination reveals that the average energy of 32.5 electron volts required to produce one ion pair can be converted into $5.24 \times 10^{13}$ electron volts per gram of air or 83.8 ergs per gram of air. It should be noted that this definition makes the roentgen a unit of dose rate (absorption) rather than a unit of intensity.

An ionization chamber such as the AN/PDR–20 which has discriminating slides for the purpose of additional alpha and beta measurements is useful as a survey instrument when the humidity is not at a point which destroys chamber insulation. Chambers with provisions for thin windows are not constructed to withstand rough usage. This instrument must be used by well-trained monitors having a close liaison with a field laboratory. Its primary usage would be in conjunction with decontamination activities.

Completely sealed ionization chambers such as the radiac meter IM–3/PD and the AN/PDR–T–1 will be standard equipment for reconnaissance and scouting parties and for damage control equipment on board ship (fig. 42). These instruments, which in some cases will be designed to read gamma dose rates which would produce lethal dosages in less than one hour (500 r/hr), will be used to monitor unusually hot areas in which urgent work must be accomplished.

Ionization chambers such as the non-self-reading pocket chambers, DT–16/PD, DT–35/PD, etc., and the self-reading quartz fibre pocket dosimeters (electroscope), IM–9/PD, IM–50/PD, etc., will be used to record individual gamma ray dosage. Trained monitors most certainly will be equipped with either the pocket dosimeter or with a pocket chamber and chamber reader. In cases where a record of dosage is required, but where it is not considered advisable for the wearer to know that dosage, the pocket chamber will be used.

Under some circumstances it is desirable to determine gamma intensities from a remote position. It is most probable that the detector element of any such instruments will utilize ionization chambers. Two possibilities present themselves for projecting instruments into a contaminated area: (a) rocket or gun fired missile, and (b) an air droppable unit. The latter is under development as the AN/USQ expendable unit with the AN/ARR–29 receiver. It has been found that the problems concerned with radiation sensitivity are minor in comparison to those of ruggedness and data telemetering. Development work is also under way to evolve airborne radiac equipment capable of interpreting ground gamma radiations from any altitude.

Ionization chamber instruments have been designed to perform the function of closing relays upon reaching predetermined dose rates of gamma radiation. Instruments of this type will be of use in limited numbers for sounding alarms, closing ventilators, etc., as in the case of the AN/ADR–1 for planes flying into a radioactive cloud. Chamber instruments can be used to record the total accumulated dose in certain restricted areas such as specific shipboard compartments, the pilot compartment of an airplane, or the interior of a tank. The AN/ADR–2 airborne gamma dosimeter is yet to be evaluated, and the AN/PDR–2 group dosimeter requires many improvements to make it satisfactory for use outside the laboratory.

Film badges will continue to record gamma exposure of personnel involved with training (fig. 43) participating in atomic weapon tests, and peacetime uses of atomic energy. Because of the many disadvantages associated with film badges, they may never be used in extensive military operations. Pocket chambers or pocket dosimeters will probably replace film badges, so that immediate spot readings of dosage can be made. If a permanent record is required for medical or legal reasons, it is relatively simple to make an automatically recording reader.

Geiger-Mueller counters such as the AN/PDR–T–2, AN/PDR–8 (series), and AN/PDR–27 are

*Figure 42. Ionization chamber being used for gamma survey work by a shipboard damage control team.*

*Figure 43. Individual dosimetry.*

Film badge and dosimeter are collected upon leaving contaminated area.


*Figure 44. Helicopter ground monitor.*

The Geiger counter is used for an air check of ground gamma contamination.

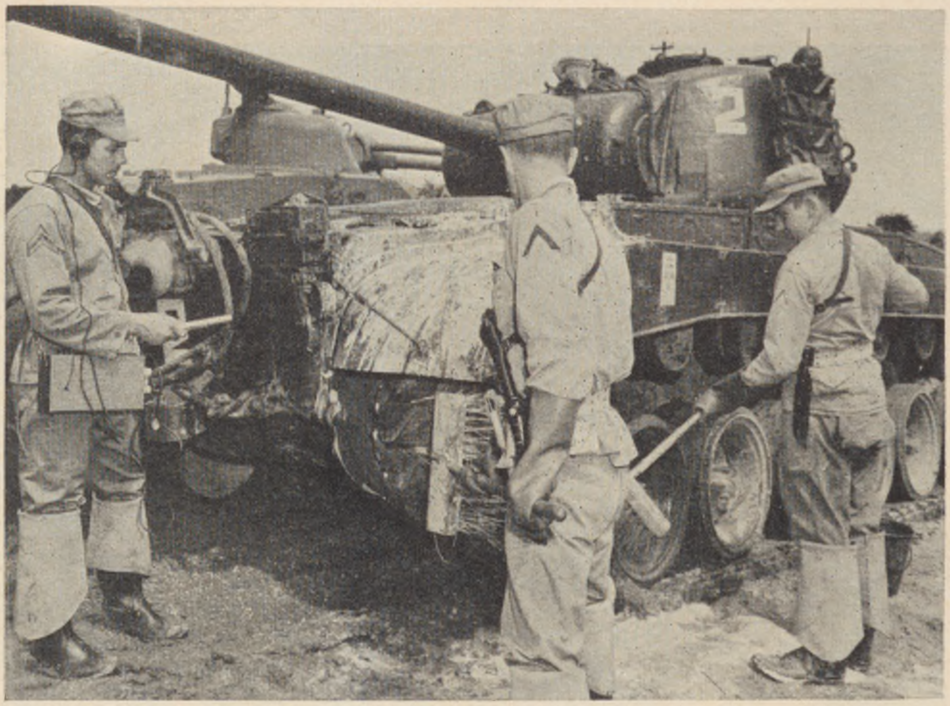

*Figure 45. Decontamination.*

The portable Geiger-Mueller detector will be a primary instrument for use in equipment decontamination.

*Figure 46. Checking hand contamination.*

The probe beta window is left open to increase sensitivity in checking clothing, hands, feet, etc. Earphones as well as meter indication are used in checking with the Geiger counter.

convenient portable instruments for gamma ray detection (fig. 44). Note that the word *detection* is used rather than *survey*. The counter range of the equipment is limited to the region from background to intensities slightly in excess of those which will give daily peace-time tolerance dosages (0.1 r) during a normal working day. As such, these instruments will have a primary use in conjunction with decontamination work (fig. 45). The probe makes them especially convenient for rapid examination of clothing, hands, feet, etc. (fig. 46). The Geiger-Mueller counter as the most sensitive gamma detector may have some usage as an early stage warning device for air-borne radioactive particles and radioactive gases. Because it counts ionizing events rather than the ionization produced in air, it is not possible to calibrate the Geiger-Mueller counter in terms of roentgens except for a definite energy spectrum. In many cases calibrations are made in milli-roentgens per hour for sources such as a standard radium sample. All other samples of radiations within the radium spectrum then can be compared in terms of milliroentgens per hour. Due to a very definite wave length dependence and the efficient counting of hard beta particles, it is unwise to use the Geiger-Mueller counter as a quantitative recorder.

The proportional counter is not used as a gamma ray measuring instrument, since the primary use of the proportional counter is for discrimination against gamma rays (and beta particles) for the purpose of alpha particle measurement.

### 14.05 The Field Laboratory

As can well be seen from an examination of previous sections, the field laboratory is probably as important as any individual instrument. Its instrumentation, working around the principles we have discussed, must work in conjunction with chemical and other analytical methods to give rapid, accurate indications of hazards. It is readily apparent that with a minor amount of training and supervision a man can take care of himself and make satisfactory gamma surveys. In the case of alpha and beta particles, highly trained monitors are required. A great amount

of decontamination work in connection with alpha and beta emitters will be directly tied into findings by the laboratory. The present designs of radiac equipment used for the detection of alpha and beta radiations do not lend themselves to ruggedization and these instruments may be used most properly in operations directly tied to a field laboratory. Some extremely important functions such as the examination of drinking water (fig. 47) can be handled only with very special laboratory techniques.

Having located radioactive areas and evaluated the immediate hazard, the laboratory can be used to determine how long the areas will remain dangerous and what measures, such as covering with earth, etc., are required prior to occupation or use. The field laboratory can make contributions regarding the composition, efficiency, etc., of enemy weapons.

Only through use and experimentation will all the components of a field laboratory be established. No attempt will be made to visualize the various analytical chemical equipments which will be required, but a rough guess as to instrument types is given below:

1. Scaler for beta and gamma counting. Scale of 1,000, mechanical register, and timing mechanism.
   a. Variable regulated power supply from approximately 100 to 2,500 volts.
   b. Geiger-Mueller and proportional counter probes.
   c. Special ion chambers.
2. Counting rate meter for beta and gamma sampling.
   a. Variable regulated power supply from approximately 100 to 2,500 volts.
   b. Geiger-Mueller and proportional counter probes.
   c. Variable speed strip recorder.
3. Gas flow proportional counter for alpha sampling, IM–11/UD, with scaler and register.
4. Miscellaneous accessories such as lead shields, thin window tubes, equipment for sample preparation and determination of weight, sample holders, etc.
5. Filter type dust collector and electrostatic type dust collector.
6. Photographic equipment for alpha track measurements. (Nuclear track plates.)
   a. Microscope.
7. Instrument calibration standards.
   a. Secondary standard instrument such as the radiac meter IM–7/PD quartz fibre survey meter.
   b. Calibration sources.

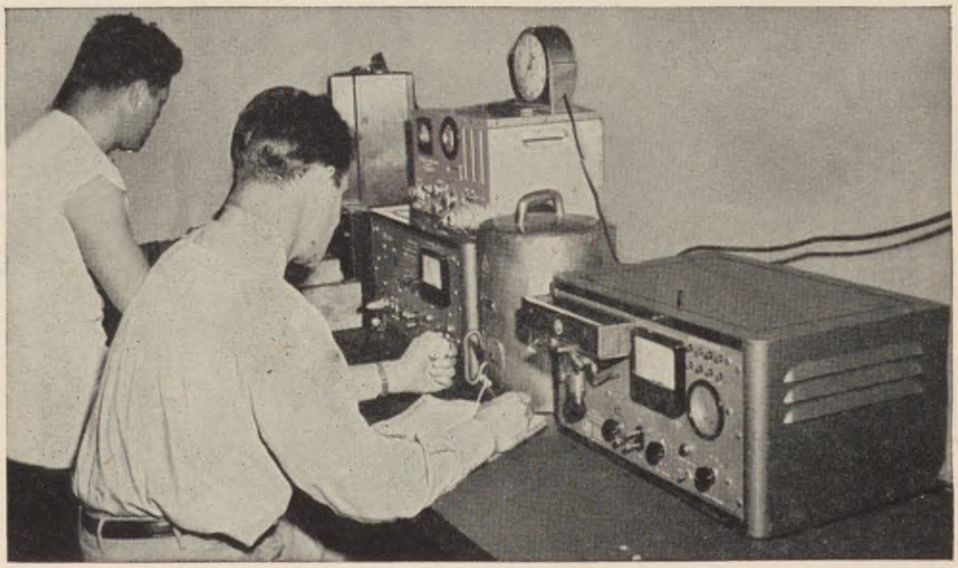

*Figure 47. Laboratory.*

The field laboratory will be a most important hazard-evaluating unit during atomic warfare.

8. Special survey instruments such as:
   a. AN/PDR–20 thin window chamber.
   b. AN/PDR–10 alpha proportional counter.

### 14.06 Other Establishments

It is anticipated that the various services will establish a number of organizations within the zone of the interior, and at perhaps some advance bases, in which practically all the radiac instruments mentioned herein will be used along with laboratory equipment with such sensitivities and delicateness as to be completely ruled out of the field laboratory category. This equipment will be used to give thorough scientific checks on the results of the field laboratories.

One very important device which will be used at any major decontamination center or at any base doing extensive work on contaminated equipment is the so-called *hand and foot counter* such as the AN/UDR–10 which is used to monitor personnel leaving working areas.

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# Chapter 15

# DESCRIPTION OF ACTUAL INSTRUMENTS

## 15.01 The Field in General

It is desired to give a detailed description of the physical properties of commercial and military instruments which are making their way throughout the Defense Establishment. In addition, some instruments which are perhaps obsolete or of no military value have been so widely discussed that they will be included to show their relation to other such equipments. Laboratory instruments are not discussed and personnel interested in these equipments are invited to examine Reference (10). For security reasons, a good number of instruments which were developed under the Manhattan District had code names. Also, some commercial model numbers have come into use. An effort is made here to correlate these names and numbers with the types of instruments we have been discussing.

The writer may not be familiar with all instruments which have been produced and are being produced; therefore, inclusion or omission of a specific manufacturer's equipment is not necessarily to be construed as either condemnation or praise. Indications will be made as to whether an instrument is obsolete, etc. The following code will be used: *"o"*—obsolete; *"i"*—in present military use; *"f"*—anticipated for future military use. A tabulation of instruments of interest is given in Appendix I.

The great majority of the instruments described herein are unclassified. Usually there will be no classification on any instruments issued for general use.

## 15.02 Pocket Dosimeters and Pocket Chambers

| | Pocket dosimeters | Pocket chambers |
|---|---|---|
| Radiation detected | Gamma | Gamma. |
| Full scale ranges | 100 mr, 200 mr, 10 r, 50 r, 100 r | 100 mr, 200 mr, 100 r, |
| Detector | Ionization chamber | Ionization chamber. |
| Volume of chamber | 2.5 cc | 5 cc (less with high range). |
| Indicator | Image of electroscope fiber on calibrated reticle of microscope. | Separate reader. |
| Weight | 1 oz | 1 oz. |
| Shape | Size of fountain pen | Size of fountain pen. |
| Dimensions | ½ in. diameter, 4—4¾ in. long | ½–⅝ in. diameter 4½—5½ in. long. |

A. Pocket Dosimeters

| Manufacturer | JAN Number | Mfg. model Number | AEC Number | Full scale reading* | Distinguishing color |
|---|---|---|---|---|---|
| A. O. Beckman Company (*f*) | IM–50/PD | | PIC–10A | 200 mr | Silver. |
| | | | | 200 mr | Black. |
| Cambridge Instrument Company (*i*). | IM–51/PD | BM 17400 | PIC–9A | 200 mr | Grey. |
| Kelley-Koett Manufacturing Company (*i*). | IM–9/PD (Set AN/PDR–3). | K–100 | PIC–7A | 200 mr | Black. |
| | | K–109 | PIC–7A1 | 200 mr | Black. |
| | | K–110 | PIC–7A2 | 200 mr | Black. |
| | IM–9A/PD | K–111 | PIC–7A3 | 200 mr | Black. |
| | IM–19/PD | K–150 (*o*), 151 (*i*) | PIC–7B | 10 r | Blue. |
| | IM–20/PD | K–160 (*o*), 161 (*i*) | PIC–7C | 50 r | Red. |
| | | K–170 (*o*), 171 | PIC–7D | 100 r | Purple. |
| Landsverk (*o*) | IM–9( )/PD (Set AN/PDR–3( )). | L–200 | PIC–7A | 200 mr | Silver. |

*A number of 100 mr dosimeters have been manufactured for use within Atomic Energy Commission laboratories.

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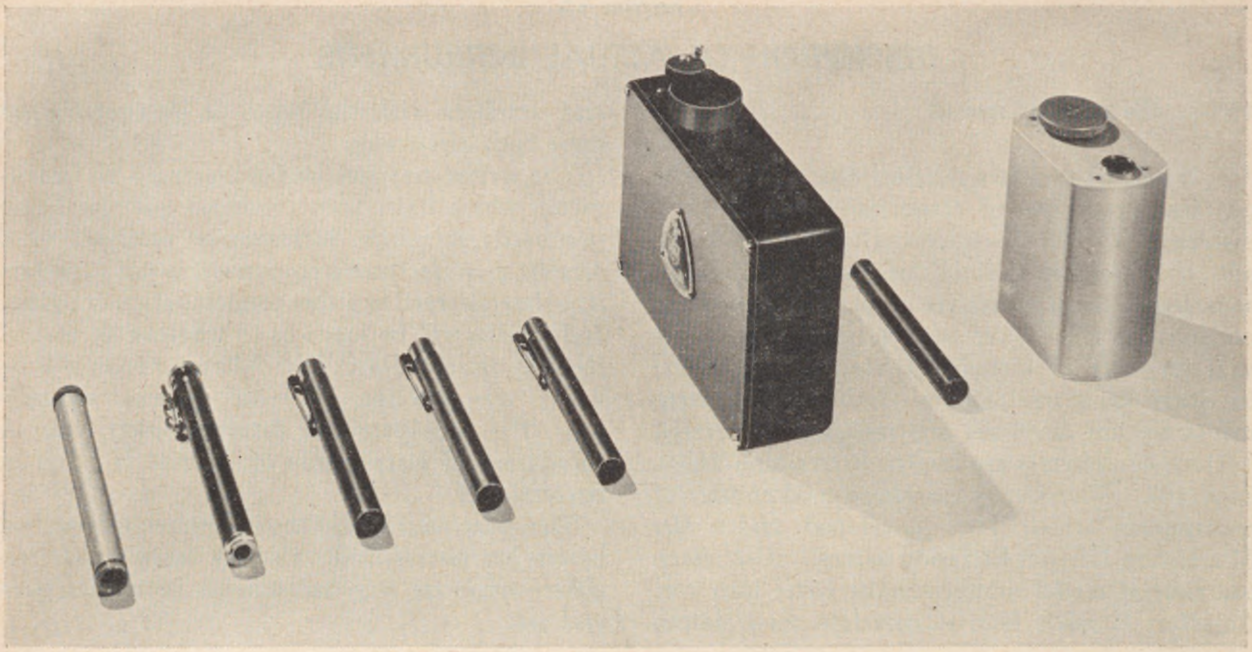


*Figure 48. Dosimeters and chargers.*

Shown from left to right are: Cambridge 200 mr; Kelley-Koett Models, K–110 (200 mr), K–151 (10 r), K–161 (50 r), K–171 (100 r); Kelley-Koett charger; Beckman 200 mr and Beckman charger.

## B. Pocket Dosimeter Chargers

| Manufacturer | JAN No. | Mfg. model number | AEC No |
|---|---|---|---|
| A. O. Beckman Co. (*f*) | | | AV–9A |
| Cambridge Instrument Company (*i*) | PP–527/PD | BM–18230 | AV–7A |
| Chatham Electronics (*i*) | PP–354/PD<br>PP–354A/PD | P–800 | |
| Kelley-Koett Mfg. Co. (*i*) | PP–311A/PD (Set AN/PDR–3)<br>PP–354B/PD. | K–135 | AV–2D |
| Landsverk (*o*) | PP–311/PD (Set AN/PDR–3) | L–300 | AV–2B |

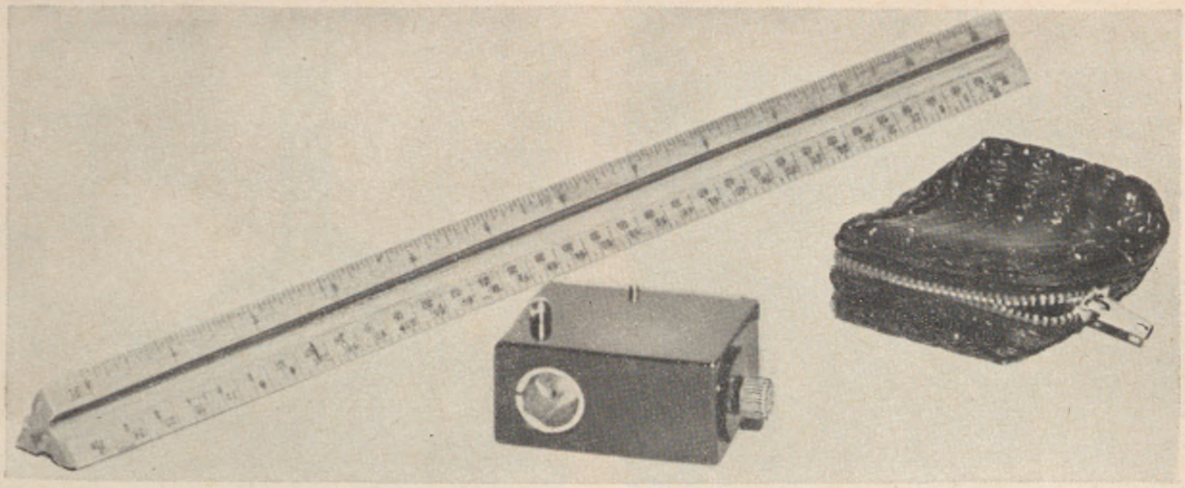


*Figure 49. Electrostatic dosimeter charger PP–354A/PD.*

This small unit is approximately 2⅜ inches wide, 1¼ inches high, and 1¾ inches deep (including protuberances). Charging is accomplished by placing the dosimeter in the hole to the left, then turning the friction knob shown on the right. See figure 6.

## C. Pocket Chambers

| Manufacturer | JAN No. | Mfg. model number | AEC No. | Full scale sensitivity* | Color |
|---|---|---|---|---|---|
| Kelley-Koett Mfg. Co. (*i*) | DT–35( )/PD (Set AN/PDR–21). | K–700 | PIC–2E | 200 mr | Black. |
| Nuclear Instrument and Chemical Co. (*i*). | DT–16A/PD (Set AN/PDR–4). | 3340 | PIC–1B | 200 mr | Grey. |
| Victoreen Instrument Co. (*i*). | DT–16/PD (Set AN/PDR–4). | 352 | PIC–2C | 200 mr | Black. |
| Victoreen Instrument Co. (*fi*) | | 353 (magnetic charging device). | | 100 r | (Black with magenta color patch). |

*A number of 100 mr pocket chambers have been manufactured for use within the Atomic Energy Commission laboratories.

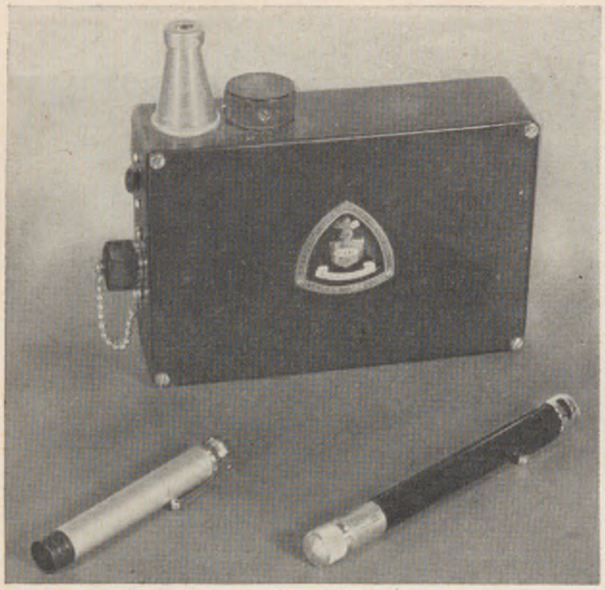


*Figure 50. Pocket chambers and charger-reader.*

Victoreen model 353 100 r (left) and model 352 (DT-16/PD) 200 mr pocket gamma chamber are shown with the Kelley-Koett model K–425 (PP–43 ( ) /PD) 200 mr charger-reader. Chambers by other manufacturers are of comparable size and shape.

### D. Pocket Chamber Charger-Reader

Tungsten fibre electrostatic voltmeter is used for charging and reading the residual charge on pocket chambers. Indication of reading comes from a projected image of the electroscope fibre on a calibrated reticule in a viewing microscope.

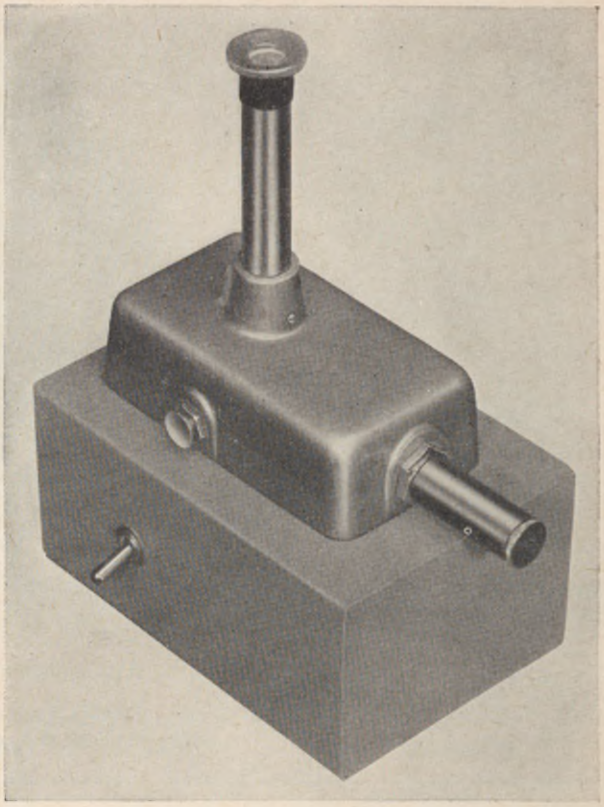


*Figure 51. Victoreen Minometer type charger-reader.*

The chamber is placed in the horizontal tube at the right of the picture. Readings are made through the vertical tube. Charging is accomplished by means of the button on the side of the instrument.

| Manufacturer | JAN No. | Mfg. model number | AEC No. | Full scale reading |
|---|---|---|---|---|
| Kelley-Koett Mfg. Co. (*i*) (quartz fibre). (2 lb., 11 oz. battery operated) | PP–43( )/PD (Set AN/PDR–21) | K–425 | AE–1B | 200 mr. |
| Victoreen Instrument Co. *Minometer* (*i*) (tungsten fibre). (6 lb., 110 v. A. C. operation) | PP–316/PD (Set AN/PDR–4) | 287 | AE–2A | 200 mr. |
| *Victoreen High range Minometer* (*f*) (tungsten fibre). (Weight, 6 lb., dimensions, 5½ in. wide x 7 in. long x 5 in. high exclusive of sight tube: 8 in. high over all. For battery operation. Magnetic charging device.) | | 392 | | 100 r. |

Direct meter reading electrostatic voltmeters are used for charging and reading 200 mr pocket chambers.

| Manufacturer | Mfg. model number | AEC No. |
|---|---|---|
| Nuclear Instrument and Chemical Co. (*i*) (10 in. long x 6 in. wide x 5½ in. high; weight, 8 lbs. For 110. v. A. C. operation. Can be used to enlarge 200 mr pocket dosimeters.) | 2050 | AE–5A |

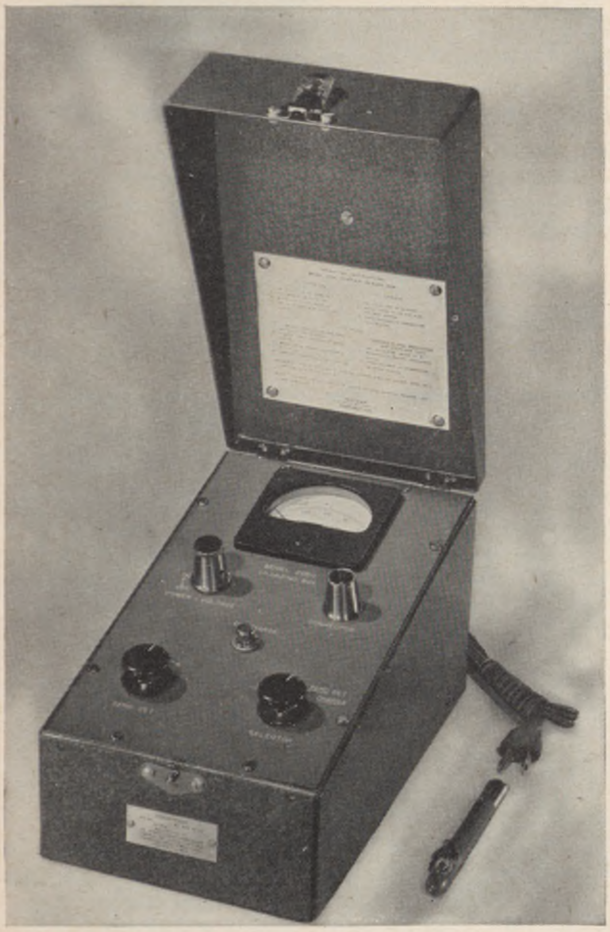


*Figure 52. Nuclear Instrument and Chemical Company model 2050 charger-reader*

A direct reading of chamber charge is given on the meter.

## 15.03 Quartz Fibre Survey Meter

The original instrument of this type (*IM–7/PD*) is the Lauritsen Electroscope manufactured commercially by the Fred C. Henson Company. As such, this is an exceedingly accurate instrument for laboratory work, but it is not well adapted to field usage.

A modified Lauritsen electroscope is manufactured by the Kelley-Koett Manufacturing Com-

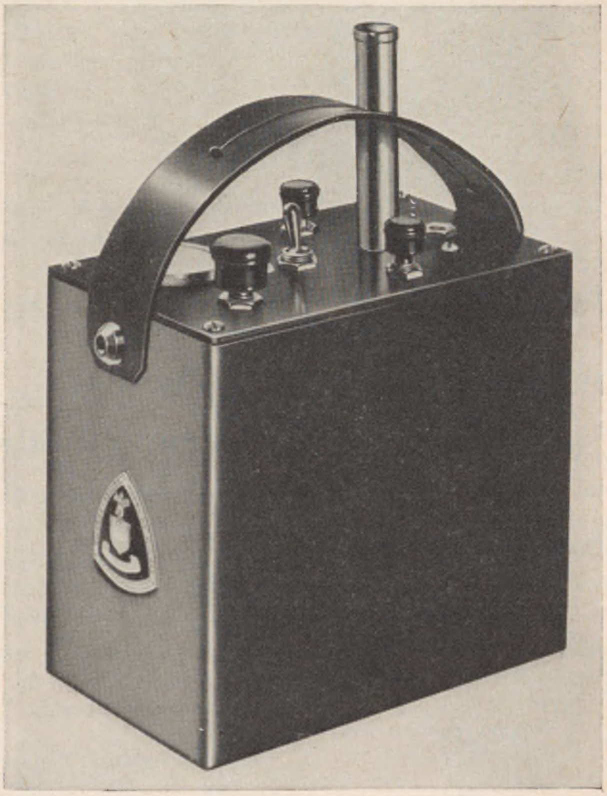


*Figure 53. Radiac Meter IM–7A/PD quartz fibre drift alpha, beta, and gamma survey meter.*

The beta window is on the far end of the instrument with the alpha window on the bottom. Readings are made through the vertical tube.

pany (previously by the Landsverk Electrometer Co.) having the following characteristics:

| | |
|---|---|
| JAN No. (*f*) | IM–7A/PD. |
| Mfg. model No. | K–320. |
| AEC No. | SIC–5A. |
| Radiation detected | Alpha, beta, gamma. |
| Scale ranges (gamma). | 0–100 mr/hr.<br>0–1000 mr/hr. |
| Detector | Ionization chamber—25 in.$^3$ |
| Indicator | Rate of drift of electroscope fibre over a calibrated reticle scale in viewing microscope. Approximately 6–8 seconds required to read true indication. An automatic flashing light timer is employed. |
| Weight | 3¼ lbs. |
| Dimensions | Main case; 6¼ in. long, 4 in. wide, 6 in. high. Microscope tube extends 2¾ in. above case. |
| Window screens | Beta—0.001 inch cellulose acetate.<br>Alpha—0.0002 inch nylon. |

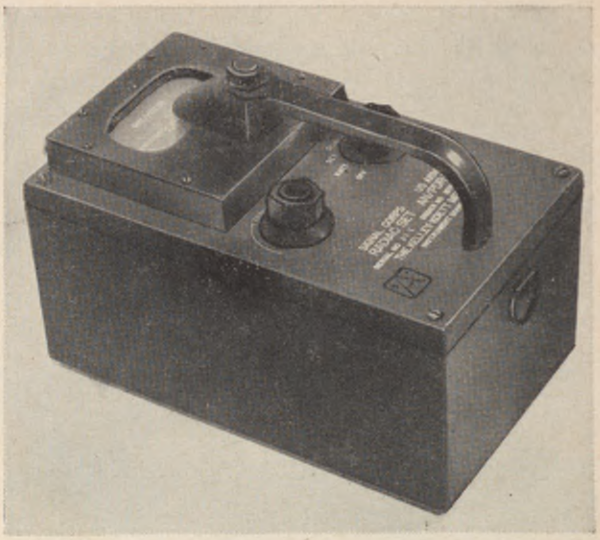


*Figure 54. AN/PDR–T–1 gamma survey ionization chamber.*

Controls are shown for zero set and range. A push-button for meter illumination is at the forward end of the carrying handle.

## 15.04 Ionization Chamber Survey Meter

### A. Gamma Ionization Chamber Survey Meter

| | | | |
|---|---|---|---|
| Manufacture | Kelly-Koett Mfg. Co. (*i*) | National Technical Labs. (*i*). | Victoreen Instrument Co. (*i*). |
| Model number: | | | |
| Manufacturers' | K–350 | MX–6 | 247A*. |
| JAN | AN/PDR–T–1 | IM–40/PD | IM–3/PD. |
| AEC | SIC–18A | SIC–15A | SIC–9B. |
| Scale ranges (mr/hr) | 0–5, 0–50, 0–500, 0–5000, 0–50,000. | 0–5, 0–50, 0–500, 0–5000 | 0–2.5*, 0–25, 0–250, 0–2500. |
| Detector | Ionization cnamber | Ionization chamber | Ionization chamber. |
| Volume (cubic inches) | 54 | 30.5 | 56. |
| Wall | Aquadag-coated polystyrene. | Aquadag-coated steel | 3/32″ polyethlene. |
| Filling | Air | Monochloro-difluoro methane. | Air. |
| Pressure | Atmospheric | 3 lb. gage | Atmospheric. |
| Indication | Meter | Meter | Meter. |
| Useful operating life (hours) | 600** | 200 | 30. |
| Weight (pounds) | 10 | 7¾ | 12⅞. |
| Shape | Rectangular | Rectangular | Rectangular with vertical cylindrical ends. |
| Dimensions (length x width x height). | 10 x 6 x 7½ including handle. | 9½ x 5 x 6 | 10 11/32 x 5 11/32 x 12 59/64. |
| Case | Welded steel with baked olive drab enamel. | Welded aluminum grey hammertone finish. | ⅛ in. cast aluminum. Baked grey enamel. |

*The Model 247B has scale ranges of 0–25, 0–250, 0–2500, and 0–25,000 mr/hr.
**Exclusive of battery for meter-illuminating light.

The AN/PDR–T–1 is the first ionization chamber gamma survey meter to be built to military specifications. These specifications were evolved from the Sandstone operational tests of commercial instruments (8) such as the 247A (IM–3/PD) and the MX–6 (IM–40/PD). The AN/PDR–T–1 is thoroughly ruggedized and will operate under any weather conditions of temperature and humidity in which the batteries will operate. The chamber is so constructed that it will operate in aircraft to an elevation of at least 36,000 feet. The meter scale changes with changes in the scale range, and a light is provided for meter illumination during night operations.

The Victoreen Instrument Company Model 247 (o) is an obsolete ionization chamber meter used extensively for survey work during Operation Crossroads. This is a large rectangular box, 12 inches long, 9 inches wide, and 10 inches high, weighing 14 pounds.

B. Beta-Gamma Survey Meters

A small light-weight, portable, gamma measuring, beta indicating survey instrument with an ionization chamber and a pistol grip was developed by the Manhattan Engineering District under the code name of *Cutie Pie.* Two such commercial instruments are outlined below, and it is known that at least one other company has produced models having some of these characteristics.

*Figure 55. National Technical Laboratories ionization chamber gamma survey meter, model MX–6 (IM–40/PD).*

The range switch is at the left of the meter end of the handle. To the right of the meter is seen the cap over a recess containing sensitivity adjustment controls. A zero control is on the top in the foreground.

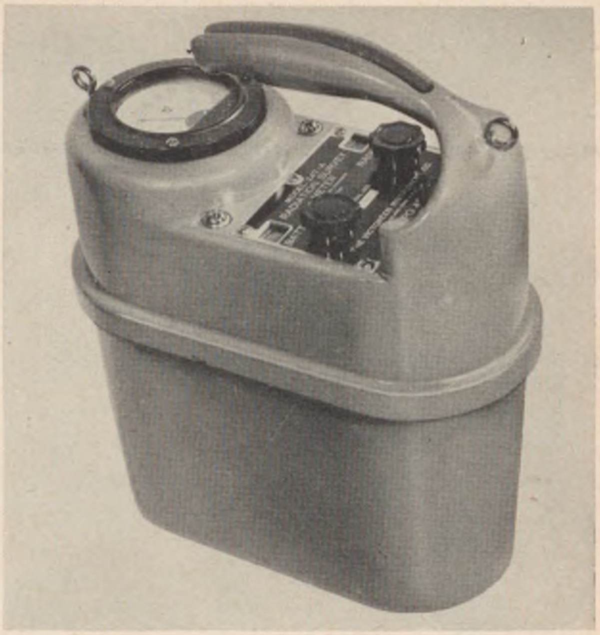


*Figure 56. Victoreen model 247A gamma chamber survey meter (IM–3/PD).*

Under the handle are controls for range selection, battery check, and zero adjustment.

| | | |
|---|---|---|
| Manufacturer | Sylvania Electric Products Co. (i). | Tracerlab, Inc. |
| AN No | IM–5/PD | IM–5/PD. |
| Mfg. model No | RD–316 | SU–A1. |
| AEC No | SIC–7A | SIC–7B. |
| Full scale gamma | 50 mr/hr | 25 mr/hr. |
| | 500 mr/hr | 250 mr/hr. |
| | 5000 mr/hr | 2500 mr/hr. |
| Chamber | 3 in. diameter | 3 in. diameter. |
| | 6 in. length | 6 in. length. |
| | Paper base, phenolic coated with aquadag. | Bakelite tube coated with aquadag. |
| Beta screen | Aluminum 0.080 in. thick. | Bakelite ⅛ in. thick. |
| Weight | 4 pounds | 4½ pounds. |
| Dimensions of main body (length x width x height) in inches. | 6½ x 3 x 5 | 6½ x 3 x 5. |

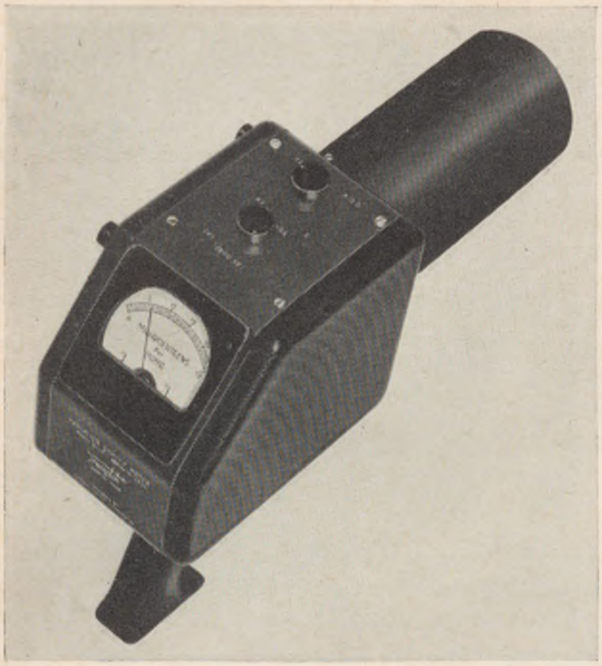


*Figure 57. Tracerlab "Cutie Pie" (IM–5/PD).*

The chamber is the barrel to the upper right. On the end of the chamber is an adjustable beta window.

The National Technical Laboratories have manufactured a medium-sized portable survey instrument utilizing an ionization chamber which will measure hard gamma radiation in roentgen rates and ionization currents due to soft gamma and beta radiations. This instrument is widely called the *Beckman Meter*.

| | |
|---|---|
| Mfg. model No. | MX–2. |
| AEC No. | SIC–11A. |
| Full scale gamma sensitivity. | 20, 50, 200, 500, 2000 mr/hr. |
| Chamber | 50 in.$^3$ bakelite coated with graphite. |
| Window | 37¾ in.$^2$, 0.010 in. celluloid. |
| Beta shield | ⅛ in. bakelite. |
| Dimensions (length x width x height) inches. | 12½ x 7½ x 6½. |
| Case | Welded aluminum with grey hammertone finish. |
| Weight | 12½ pounds. |

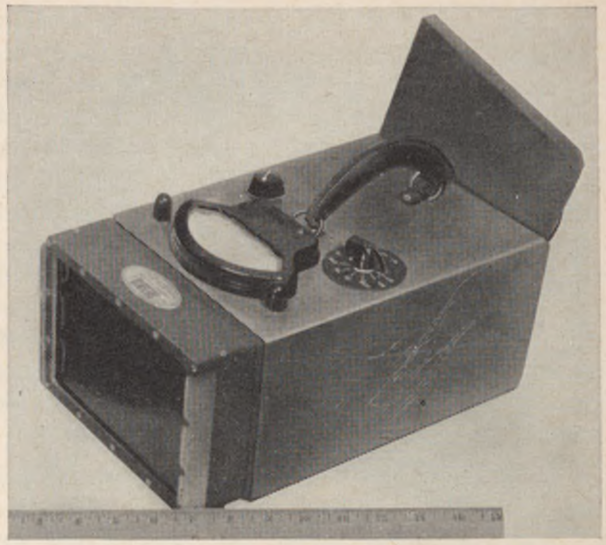


*Figure 58. National Technical Laboratories model MX–2 beta-gamma survey meter.*

The chamber can be seen on the left end of the case. The gamma shield has been removed and is showing above its holder at the right end of the case.

The Argonne National Laboratory and its predecessor, the Chicago Metallurgical Laboratory, manufactured a portable beta gamma nondiscriminating air ionization rate meter type with the detector in a probe at the end of a four-foot cable. This instrument, now obsolete, was called the *Betty Snoop* (*o*). As a matter of identification, this instrument was assigned the following numbers:

| | |
|---|---|
| JAN Number | AN/PDR–9 |
| Mfg. Model Number | C2M10 |
| AEC Number | SIC–4A |

C. Alpha-Beta-Gamma Chamber Survey Meter

A number of medium-sized instruments have been manufactured utilizing thin windows on one side of a chamber and, in some cases, discriminating slides to give indications of alpha-beta-gamma radiations in terms of roentgen rates. These equipments will measure ionization currents due to soft gamma, beta, and alpha radiations.

| | | | | | |
|---|---|---|---|---|---|
| Code Name | *Juno* | *Pluto* (*o*) (*Sandy*) | *Zeuto* | *Hanford Zeuto* | *Zeus** (*o*). |
| Manufacturer | Hanford | Argonne | Victoreen | Kelley Koett Mfg. Co. | Rauland. |
| Mfg. model No | | CIMI | 356 | K–340 | Z–100. |
| JAN No | | | IM–4/PD | | |
| AEC No | SIC–17A | SIC–1A | SIC–2A | SIC–2C | |
| Function | Discriminating | Non-discriminating | Non-discriminating. | Non-discriminating | Discriminating. |
| Full scale gamma | 50 mr/hr<br>500 mr/hr.<br>5000 mr/hr. | Primarily used for alpha with indication a function of calibration. | 4 mr/hr<br>40 mr/hr. | Sensitivity: 5,000, 50,000, and 500,000 per minute. | 25 mr/hr.<br>100 mr/hr.<br>500 mr/hr.<br>2500 mr/hr. |
| Indication | Meter | Meter | Meter | Meter | Meter. |
| Weight (pounds) | 5 | 8 | 6 | 6 | 10⅓. |
| Dimensions (length x width x height) in inches. | 9 x 5¼ x 4 | 10½ x 5½ x 3½ | 9½ x 6 x 5 | 9½ x 6 x 5 | 13 x 10⅜ x 5⅜. |

*In the Model Z–100A (*o*), the Rauland Manufacturing Company has left off the thin window and has produced a gamma-only chamber which may, in some cases, be referred to as the *Zeus*.

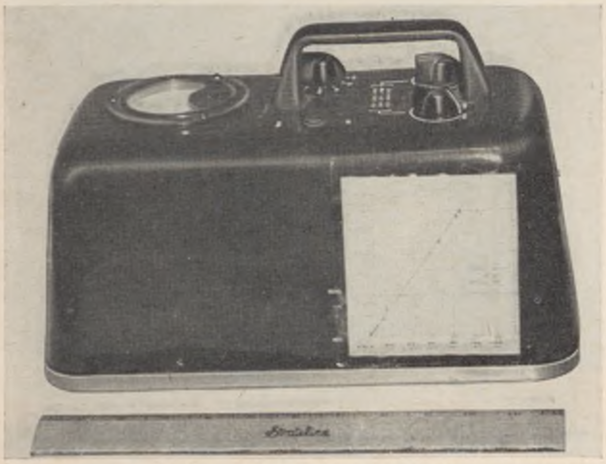


*Figure 59. Rauland "Zeus".*

The chamber occupies a space under the meter with the thin window on the bottom of the instrument case.

The General Electric Company has manufactured a Zeus-type radiac set to military specifications which is still to be fully evaluated:

| | |
|---|---|
| JAN No | AN/PDR–20 (*f*). |
| Full scale gamma (r/hr) | 500, 2.5, .25, .025. |
| Weight | 10 pounds. |
| Dimensions (length x width x height) | 9¼ x 6 x 6⅞. |
| Beta shield | ⅛ in. bakelite. |
| Alpha shield | 0.003 in. aluminum. |
| Window area | 65% of 17 in². |
| Volume of chamber | 88 in.³ |

### D. Ionization Chamber Group Dosimeter

Several instruments have been devised to make integrated gamma dosage records. The Victoreen Instrument Company manufactures two such instruments under the trade name of *Proteximeter* which have the following characteristics:

| | | |
|---|---|---|
| JAN No | AN/PDR–2 (*i*) | |
| Mfg. model No | 300 | 392 (*i*). |
| AEC No | MIC–4A | |
| Full scale reading | 200 mr | 50 r. |
| Chamber | ¹⁄₁₆ in. polythylene wall 3 in. high x 3 in. diameter. | Magenta colored. |
| Battery life | 300 hr. continuous reading. | |
| Case | Cast aluminum with grey crackle finish. | Scale colored magenta. |
| Dimensions (length x width x height) in inches. | Case 9 x 4 x 4½ exclusive of chamber, 7 in. over all. | 9 x 4 x 4½ exclusive of chamber, 7 in. overall height. |
| Weight | 5 pounds | 5¼ pounds. |

A gravity switch in the top of the AN/PDR–2 is designed to discharge the chamber when the instrument is inverted. A manual switch has been placed in the Model 392 to prevent accidental discharge as the result of inversion, vibration, or shock. The chamber may be detached for use away from the instrument base (see fig. 12).

### E. Ionization Chamber Instruments for Aircraft Use

#### a. Gamma Intensity Meter

Instruments which may be used to indicate dose rate and dosage within aircraft are now reaching the prototype evaluation stage. Such an instrument is the AN/ADR–1. The AN/ADR–1 (XN–2) as it now exists consists of four units of approximately the following types and sizes:

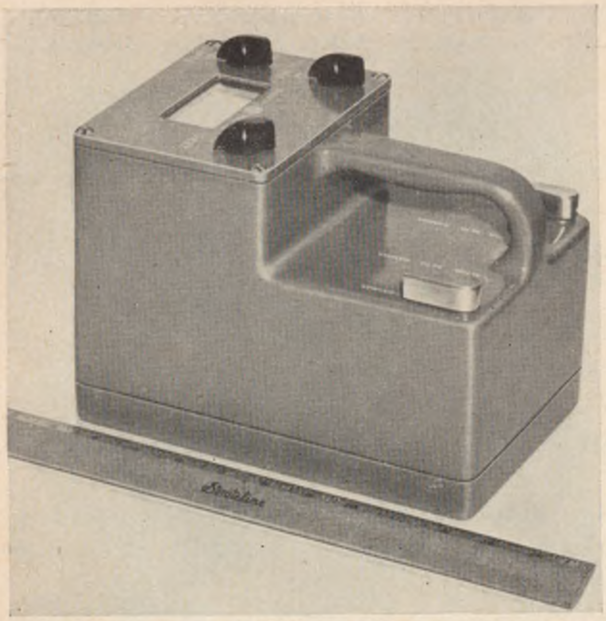


*Figure 60. The AN/PDR–20(XN–1) an experimental model military "Zeus".*

Beta and gamma shields are moved by means of the controls on either side of the handle.

(1) An indicator of the smallest standard size intended for panel installation, having the following dimensions: 2½x 2½x4¾ inches, with a 1⅞-inch scale.

(2) Flight control box of dimensions roughly 4 x 6 x 4 inches.

(3) Power amplifier of dimensions 10 x 8 x 15 inches.

(4) Receiver of dimensions roughly 10 x 7 x 5 inches.

The total weight is presently between 38 and 40 pounds.

The indicator includes the following characteristics: Two scales; one 0–20 mr/hr, and the other 0–2000 mr/hr. On one side of the scale a yellow light indicates dose rates of 4 mr/hr. On the other side of the scale a red light indicates 20 mr/hr. At the 20 mr/hr dose rates the meter scale automatically changes, and other relay contacts are actuated.

The receiver compartment contains two ionization chambers of noncoated stainless steel and filled with about 10 ml of argon gas at 50 atmospheres pressure. One chamber actuates the 0–20 mr/hr meter scale, while the other chamber actuates the 0–2000 mr/hr meter scale. A radium calibration source actuated by the flight control box checks instrument operation on the 0–20 mr/hr scale.

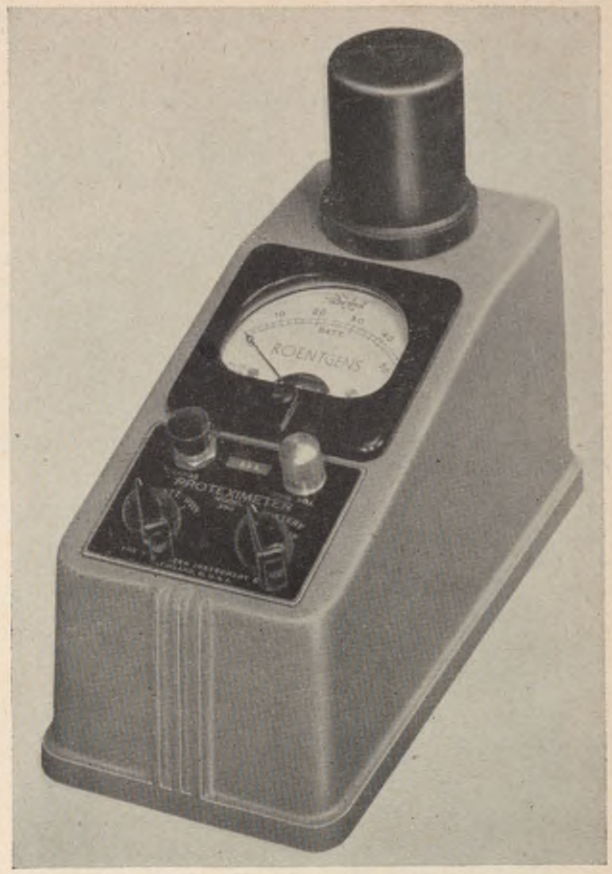



*Figure 61. Victoreen high-range "Proteximeter".*

The chamber is shown above the meter. A total of 50 roentgen gamma may be recorded.

Controls are provided to actuate external circuits to close ventilators, open oxygen valves, insert filters, etc., at predetermined levels of radiation intensity.

b. Gamma Telemetering System

Equipments capable of being dropped or projected into contaminated areas to relay information on dose rate and rate of decay are well advanced in development. One such unit which may be dropped from aircraft is the AN/USQ–1.

F. Neutron Chamber

In order to make a complete presentation of nomenclature, mention is made of the *Chang* and *Eng* portable survey instrument designed to measure fast neutrons in the presence of gamma radiation. The Chang and Eng consists of two ionization chambers, connected in parallel, with a quartz fibre electrometer to measure the difference of the ionization current in the two chambers. One of the chambers indicates neutrons plus

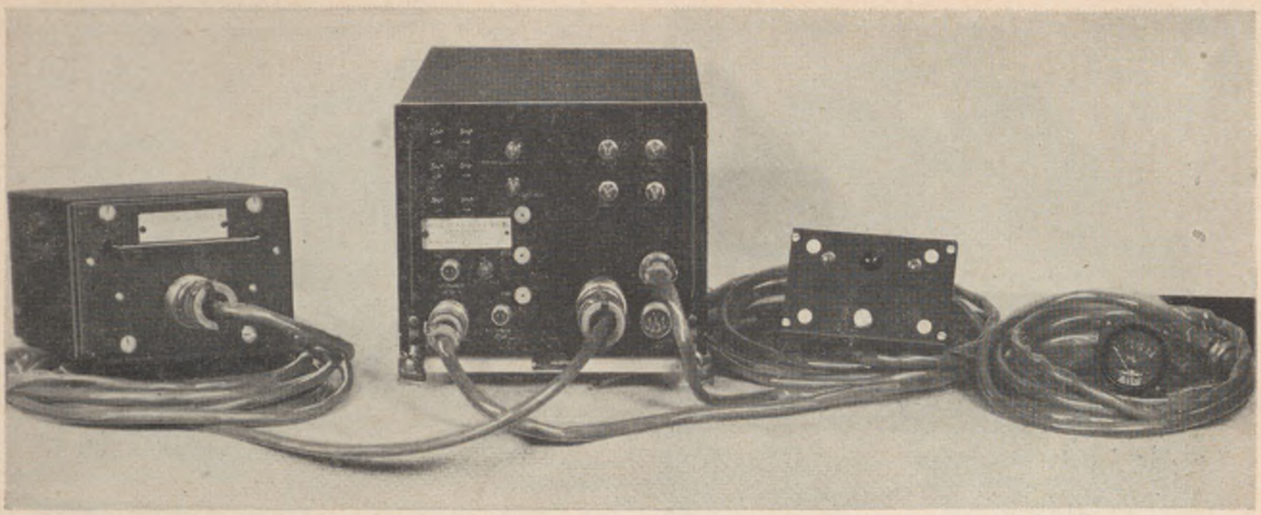


*Figure 62. AN/ADR-1(XN-2) airborne radiation detection system.*

From left to right; (a) Detector Unit, (b) Power Supply, Amplifier Unit, (c) Control Console, and (d) Panel Meter with automatic changeable scale and indicator lights.

gamma rays, the other chamber indicates only gamma rays. As a result the gamma ionization currents can be made to cancel so that the only indication is the ionization current indication of fast neutron exposure.

## 15.05 Portable Alpha Proportional Counter

The Manhattan Engineering District developed two portable alpha proportional counters for laboratory survey work. These instruments have virtually no usage within the military establishment and only minor commercial usage.

| | | |
|---|---|---|
| Instrument | *Poppy* (*Walkie Poppy*). | *Pee Wee* (*i*). |
| Design | Argonne National Laboratory. | Los Alamos Scientific Laboratory. |
| Manufacture | Argonne National Laboratory. | Nuclear Instrument and Chemical Co. |
| AEC No | SPC-1A | SPC-1C. |
| Mfg. No | CLM-41 | 2111. |
| Case | | Grey anodized aluminum. |
| Shape | | Rectangular. |
| Dimensions | | 11⅞ x 5¾ x 8. |
| Weight | | 16 pounds. |
| Scale readings (counts per minute). | 0–30,000 0–3,000. | 0–2,000, 0–20,000. |
| Indication | Output meter crystal headphones. | Output meter headphones. |

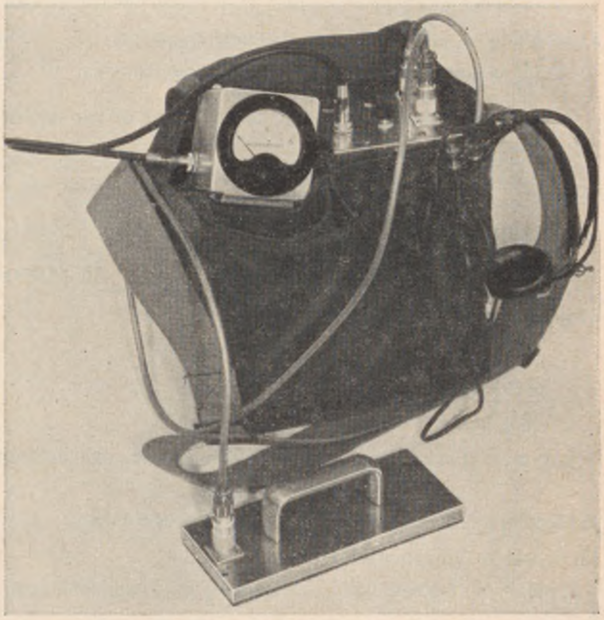


*Figure 63. Original "Poppy" type portable alpha proportional counter.*

A flat probe may be seen in the foreground.

Both instruments are important, since they are the forerunners of modern equipment being developed by the Atomic Energy Commission and the Department of Defense.

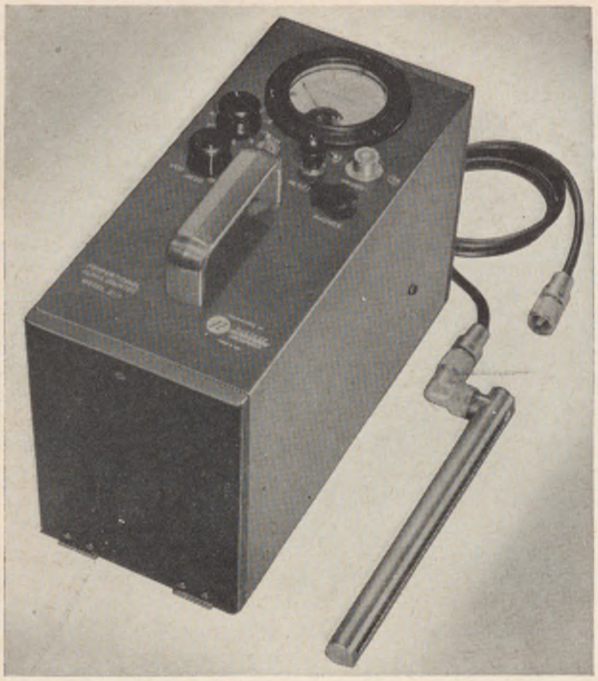
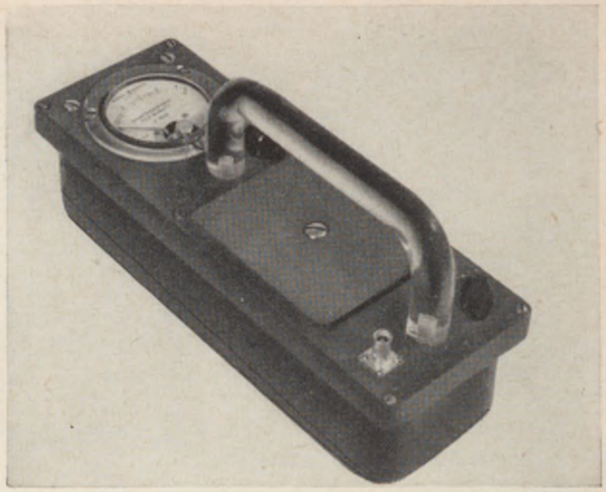


*Figure 64. Nuclear Instrument and Chemical Co. "Pee Wee" proportional alpha counter model 2111.*

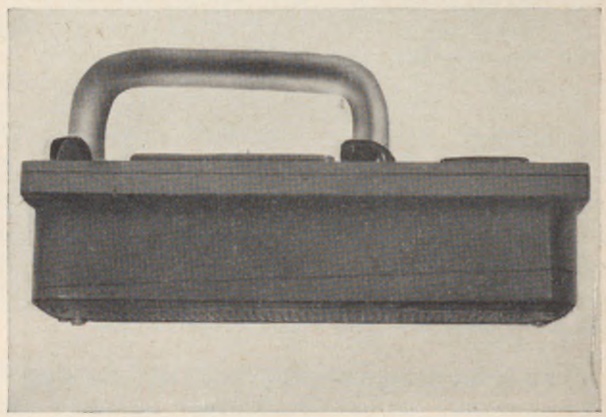
A pencil type probe is shown to the right of the instrument case.

An improved *Poppy* known as the AN/PDR–10 (*f*) is in the latter stage of development. A prototype form is shown in figure 65.

| | |
|---|---|
| Full Scale Meter Readings (counts per minute) | 1,000, 10,000. |
| Window | Plyofilm window on bottom of case. |
| Indication | Meter and earphones. |
| Dimensions (length x width x height in inches) | 12½ x 4½ x 2½ (approximate). |
| Weight | Approximately 5 lbs. |



*a. Top view of the AN/PDR–10 showing meter and controls. Earphones are also used for indication.*



*b. Bottom view of the AN/PDR–10 showing holes in the bottom of the case covering the thin window. Several parallel wires are used for election collection.*

*Figure 65. AN/PDR–10 "Poppy" type proportional alpha detector.*

### 15.06 Geiger-Mueller Counters

A. Commercial Portable Detectors.

Portable Geiger-Mueller counters have reached the commercial market in a great number of different shapes and sizes. Among the better known survey instruments are these:

| | | | | |
|---|---|---|---|---|
| Manufacturer | El Tronics (*i*) | National Technical Labs. (*i*). | Nuclear Instrument and Chem Co. (*i*) (*o*). | Victoreen Instrument Co. (*i*) (*o*). |
| JAN number | AN/PDR-26 | IM-39/PD | IM-8( )/PD (Set AN/PDR-7). | IM-1A/PD (Set AN/PDR-5). |
| Mfg. model No | SM3 | MX-5 | 2610 | 263A. |
| AEC No | SGM-18A | SGM-15A | SGM-4B | SGM-2B. |
| Radiations | Beta-gamma | Beta-gamma | Beta-gamma | Beta-gamma. |
| GM tube | RCL MK-1 MDL 20 | RCL MK-1 MDL 20 | NICC D-12 | Victoreen VG-13. |
| Wall thickness ($mg/cm^2$). | Glass 30 plastic 15 | Glass 30, plastic 17 | Glass 35 | Glass 30. |
| Probe opening (inches) | (4) ¼ x ⅞ (1) ¼ x 1⅞ | 60% of 3 x circumference. | 66% of 2½ x circumference. | 80% of 2 x 2½. |
| Dimensions (length x diameter, inches). | 7¼ x ⅞ | 8 x 1 | 9½ x 1 | 9 x 1½. |
| Probe cable length (inches). | 30 | 30 | 36 | 24. |
| Beta shield | 2mm brass | 1/32″ brass | 1/32″ brass | 1/32″ brass. |
| Indicator | Meter, earphone (magnetic). | Meter, earphone (magnetic). | Meter, earphone (crystal). | Meter, earphone (crystal). |
| Scale ranges (mr/hr) | 0-0.2, 0-2.0, 0-20 | 0-0.2, 0-2.0, 0-20 | 0-0.2, 0-2.0, 0-20 | 0-0.2, 0-2.0, 0-20. |
| Useful operating life (hrs.). | 200 | 400 | 200 | 150. |
| Weight (lbs.) | 8¾ | 9.6 | 11.6 | 13.4. |
| Shape | Rectangular | Rectangular | Rectangular | Rectangular. |
| Case dimensions (length x width x height in inches). | 9¾ x 5 x 6 | 9½ x 5 x 6 | 11 x 6 x 4 | 12¼ x 3¼ x 8½. |
| Case material | Welded aluminum | Welded aluminum grey hammertone finish. | Welded steel grey enamel. | Grey enamel. |
| High voltage supply | 3-300 v batteries | 3-300 v batteries | 3-300 v batteries | 3-300 v batteries (one 900 v battery in some). |

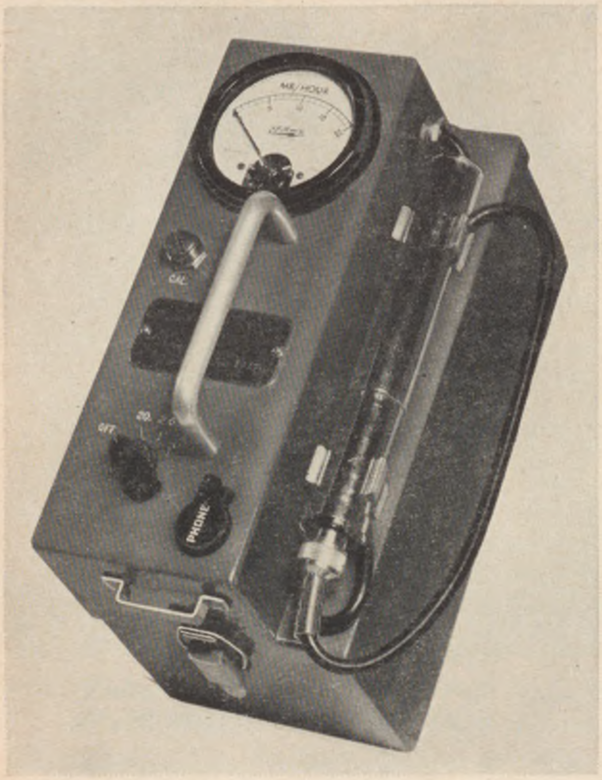


*Figure 66. El-Tronics model SM–3 Geiger counter (AN/PDR–26).*

The probe is in the well along the side of the top.

The IM–39/PD, IM–8( )/PD, and IM–1A/PD received field tests during Operation Sandstone (8) which resulted in the specifications for the AN/PDR–T–2. This instrument will be described in the paragraph on military Geiger-Mueller counters. Other commercial instruments which have had some military use and which should be noted are:

Victoreen Instrument Company Model X–263, IM–2( )/PD (Set AN/PDR–6) (*o*). This instrument is a small light-weight, low voltage (300 v) Geiger-Mueller survey meter without a probe and is now obsolete because of unsatisfactory performance.

The Victoreen Instrument Company Model 263, IM–1( )/PD (Set AN/PDR–5) (*o*), the predecessor to the Model 263A (IM–1A/PD). This instrument has nearly the same physical characteristics but is not as fully refined as the 263A. A Model 263B, which involves further improvements, has recently been issued.

A great number of light-weight beta-gamma sensitive Geiger-Mueller counters have been manufactured as prospector instruments. In many cases these instruments do not have count rate circuits and output meters and utilize earphones for their means of indication. Typical instruments are the Midwest Electronic Laboratories RD–P; Radiation Counter Laboratories Mark 11, Model 21, and the National Technical Laboratories MX–8.

One of the original Manhattan project portable, beta-gamma detecting survey instruments, utilizing a Geiger-Mueller tube probe supplied with high voltage from a vacuum tube, oscillator and rectifier circuit received the code name *walkie talkie* (*o*). The *walkie squawkie* (*o*) was the same type of instrument. The difference being the talkie used headphones while the squawkie utilized a loud-speaker.

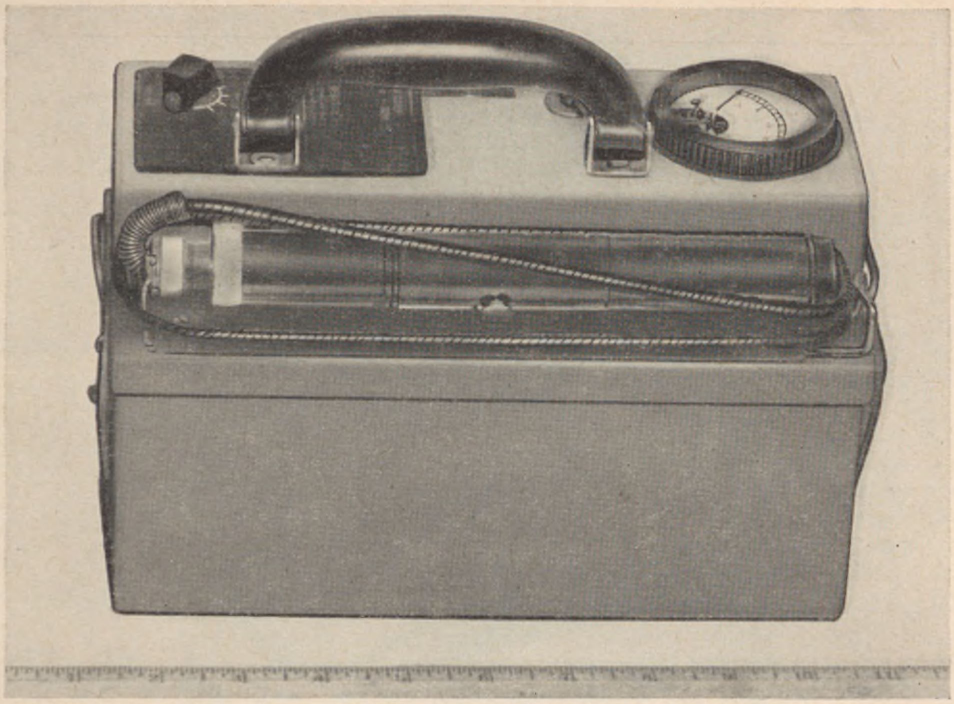


*Figure 67. National Technical Laboratories model MX–5 Geiger Counter (IM–39/PD).*

The probe is mounted horizontally in the well along the top of the case. The range is to the left of the handle. The phone jack and zero adjustment are out of sight at mid-case.

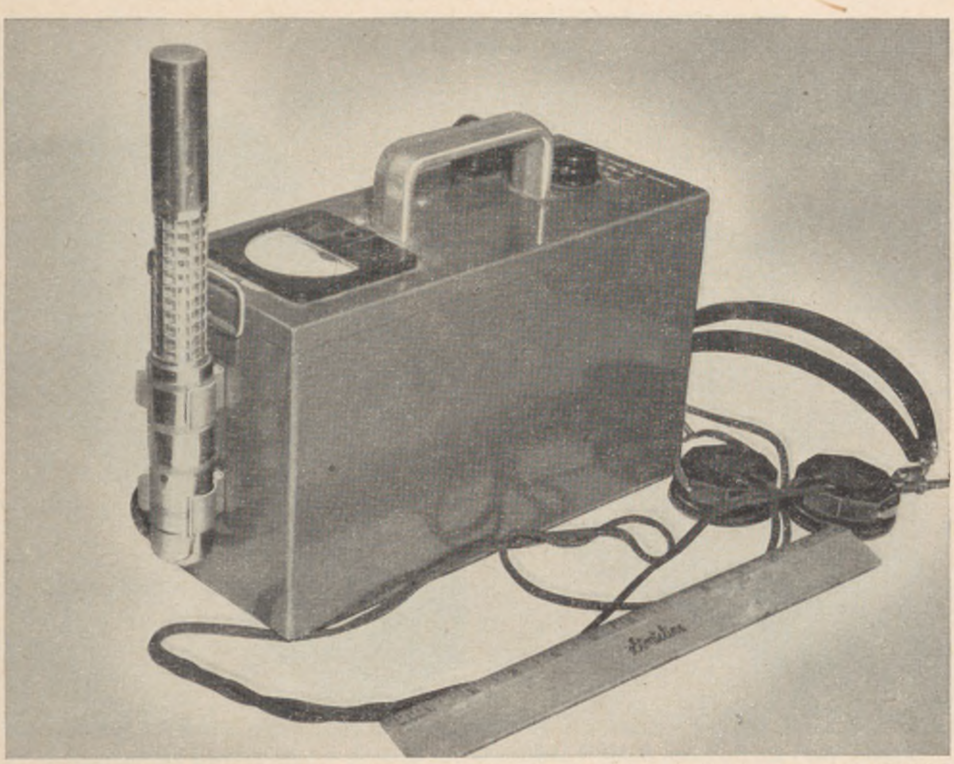


*Figure 68. Nuclear Instrument and Chemical Company model 2610 Geiger counter (AN/PDR–7).*

The probe is shown mounted in clips on the end of the instrument. The probe beta shield is open.

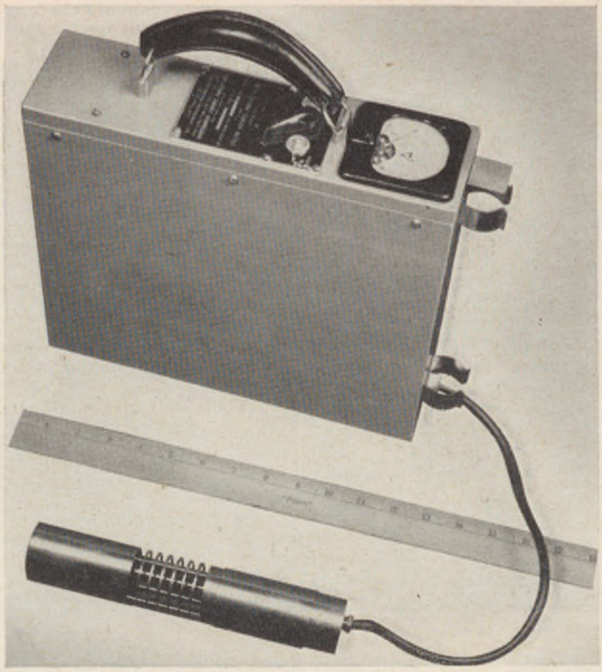


*Figure 69. Victoreen Instrument Company model 263A Geiger counter (AN/PDR–5).*

The probe (foreground) is carried in the brackets at one end of the instrument case. The switch and phone jack are located mid-case under the handle.

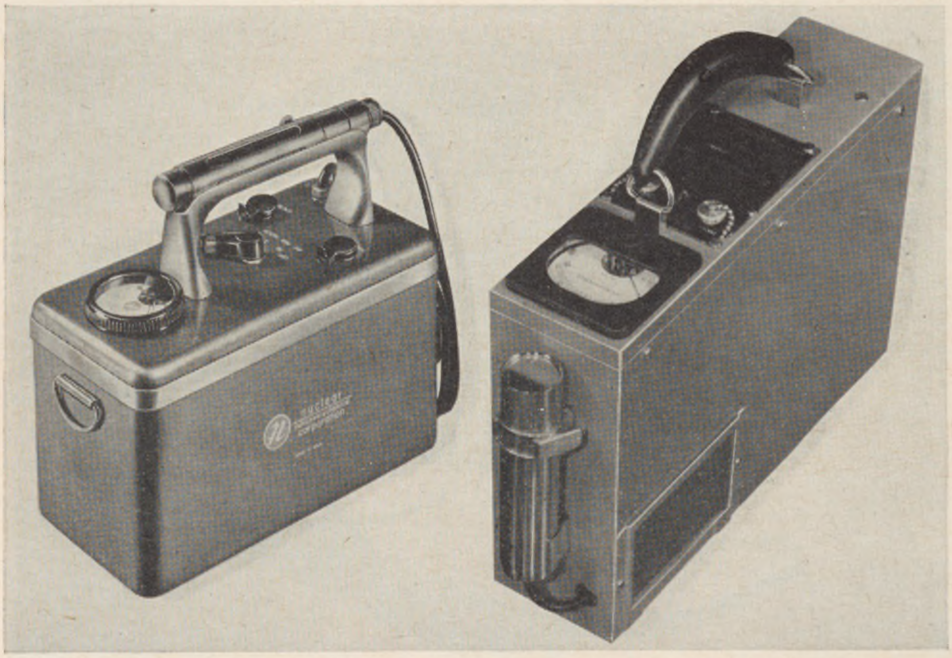
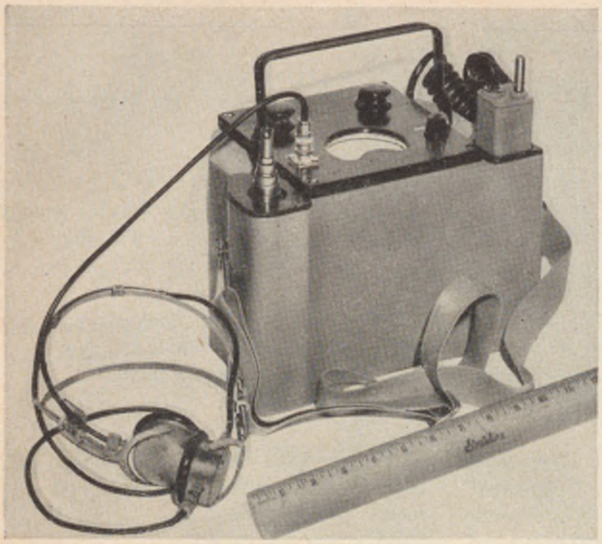


*Figure 70. Recent commercial improvements in portable Geiger-Mueller survey meters.*

Left; the Nuclear Instrument and Chemical Company Model 2610A with the probe held in a recess in the handle. Right; the Victoreen Instrument Company Model 263B which involves some improvements over Models 263 and 263A.

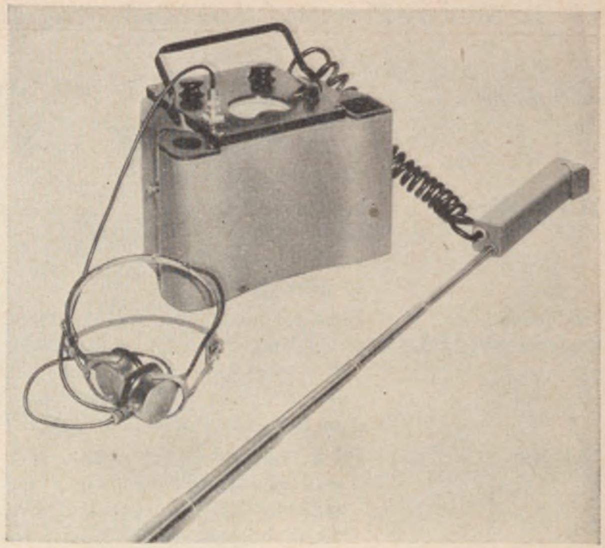
## B. Military Portable Geiger-Mueller Detectors

| | | | | |
|---|---|---|---|---|
| JAN number | a. AN/PDR–8 (*f*)<br>b. AN/PDR–8A (*f*)<br>c. AN/PDR–8B (*f*)<br>d. AN/PDR–8C (*f*) | AN/PDR–15 (*f*) | AN/PDR–27 (*i*) | AN/PDR–T–2 (*i*). |
| Manufacturer | a. Hoffman<br>b. R. C. A.<br>c. Hoffman<br>d. Admiral | ---------- | General Electric | El-Tronics (model PR–2). |
| Radiation | Beta-gamma | Beta-gamma | Beta-gamma | Beta-gamma. |
| Scale ranges (mr/hr) | a. Calibrated in r/24 hr. b, c, d. 0–0.5, 0–5.0, 0–50, 0–500 (beta indication on first two scales). | 0–0.5, 0–5.0, 0–50, 0–500 (beta indication on first two scales). | 0–0.5, 0–5.0, 0–50, 0–500 (beta indication on first two scales). | 0–0.5, 0–5.0, 0–50. |
| Detector | BS–1; halogen-filled mica end window (first two scales). BS–2, low sensitivity halogen tube (3rd and 4th scale). | BS–1; halogen-filled mica end window (first two scales). BS–2, low sensitivity halogen tube (3rd and 4th scale). | BS–1; halogen-filled mica end window (first two scales). BS–2, low sensitivity halogen tube (3rd and 4th scale). | RCL MK–1 Mdl 21. |
| Beta window ($mg/cm^2$). | 3–4 | 3–4 | 3–4 | 30. |
| Window area ($in.^2$) | 0.44 | 0.44 | 0.44 | 8 openings ½ in. x 1 7/16 in. |
| Indicator | Meter plus headphones | Meter plus headphones. | Meter plus headphones. | Meter plus headphones. |
| Probe dimensions | 8 x 1⅜ x 1⅜ in | 7¾ x 1⅜ x in. dia | 8 x 1⅜ x 1⅜ in | 8⅝ x ⅞ in. dia. |
| Length of probe cable. | 60 in | 60 in | 60 in | 36 in. |
| Form factor | Kidney-shape | Rectangular "flat iron" | Rectangular | Rectangular. |
| Dimensions (length x width x height in inches). | 10 x 6½ x 7 | 11¼ x 4⅜ x 3½ | 9¼ x 5 3/16 x 4½ | 10 x 6 x 7. |
| Weight (pounds) | a. 14.1<br>b. 11.5<br>c. 12.8<br>d. 11.5 | 11 | 10.2 | 9.5. |
| Power supply | a. Electronic vibrator<br>b. Vibrator (sub-miniature tubes).<br>c. Neon oscillator<br>d. Vibrator (sub-miniature tubes). | Electronic vibrator | Neon oscillator (plug in electronic unit). | 3–300 v batteries. |



*a. Kidney-shaped radiac set AN/PDR–8.*

The tube is vertically held in a box on the right of the instrument. The extension pole is collapsed in a box on the left. Carrying straps are shown.



*b. AN/PDR–8 with probe.*

The extension pole with the end window tube probe is shown.

*Figure 71. Geiger counters AN/PDR–8 (series).*

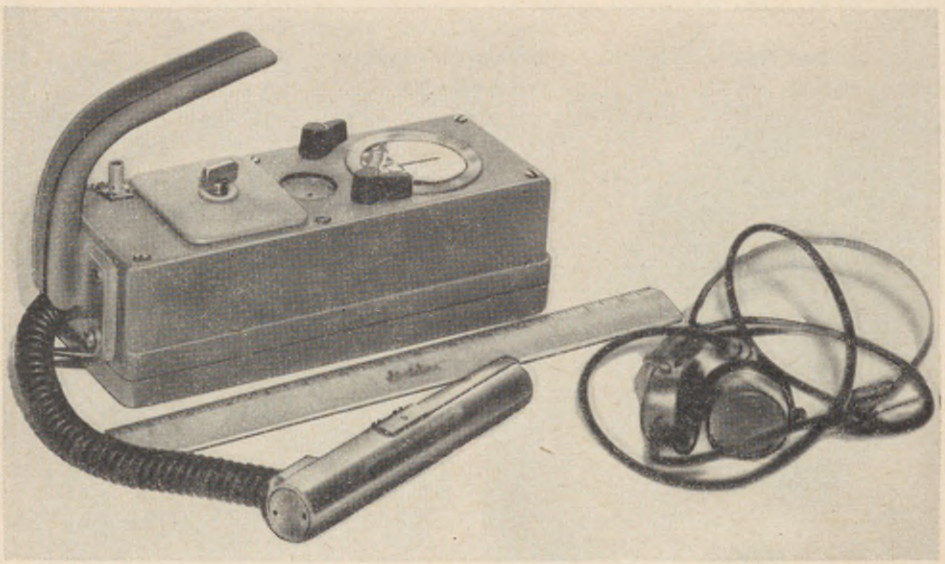
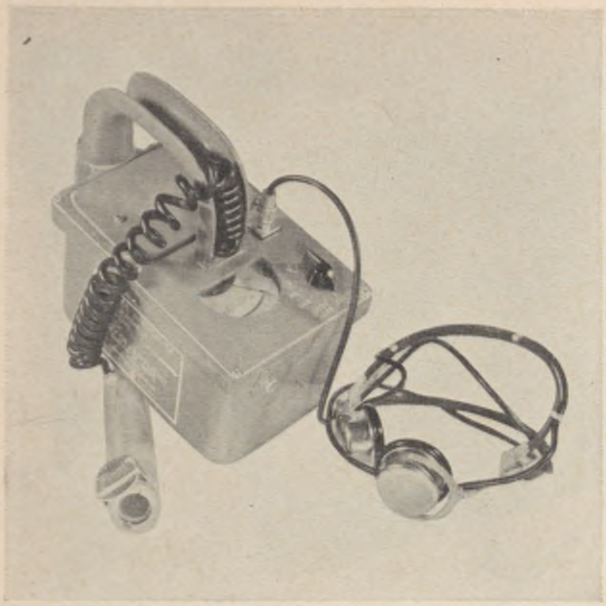
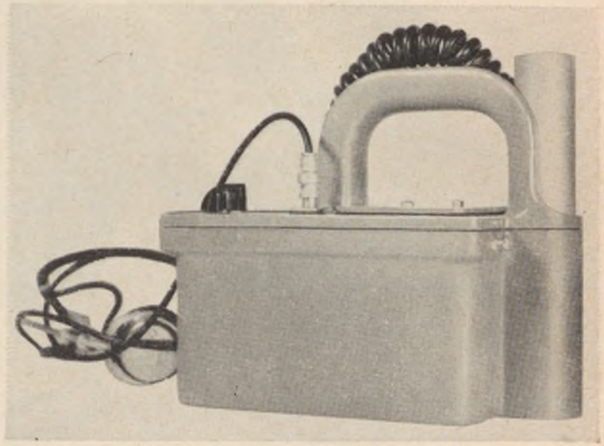


*Figure 72. Geiger counter AN/PDR–15.*

The end window tube holder is placed in the hole between the two control knobs when not used at a distance from the body of the instrument.



*a. The probe case with thin end window Geiger tube is shown in foreground.*



*b. Side view of case with probe vertical in holder at the right end of instrument.*

*Figure 73. Radiac set AN/PDR–27.*

This instrument was originally known as the AN/PDR–8E.

These radiac equipments have automatic scale number-changing devices with changes in scale ranges. The AN/PDR–T–2 has an illuminated dial for night operation. The AN/PDR–8 series is supplied with a fish-pole type of extension (36 inches) for probe examinations at a distance from the instrument (see fig. 29). The probe of the AN/PDR–15, and also of the AN/PDR–27, is carried in a vertical hole through the instrument case, so that when the instrument is being held by the handle, the beta window is exposed to the ground to facilitate ground beta survey work. The AN/PDR–T–2 is intended as an interim training instrument and is the combined result of the Sandstone evaluations (8).

C. Monitors Utilizing Geiger Detection

a. A number of instruments are manufactured commercially as monitors for detecting gamma radiation. The majority give an audible signal, either as amplified Geiger clicks or as a buzz, when a predetermined level of radiation is reached, and as a result some have been called *squawkers*, etc. The Geophysical Instrument Company Model 600 is a good example. This instrument causes an alarm to sound intermittently at gamma intensities of about 0.1 r with the frequency increasing to continuous alarm at 0.14 r.

b. Probably the most important of the presently available monitoring instruments are the *hand and foot* monitors (*i*) such as the commercial equipment manufactured by the Kelley-Koett Manufacturing Company:

| | |
|---|---|
| JAN number | AN/UDR–3. |
| Mfg. model number | K–240. |
| AEC number | CGM–17B. |
| Dimensions | 67 in. high, 36½ in. wide, 22 in. deep. |
| Weight | 600 pounds. |
| Power | 115 v 60 cycle A. C. |

There are five scaling systems with registers as follows: 2 GM tubes for palm and back of each hand (4 systems with a total of 8 tubes) and 4 GM tubes for the feet. An over-all total of 12 GM tubes. The tubes are sensitive to beta particles having energies greater than 160 Kev. The approximate warning level is 15 counts (including background) in 24 seconds for the feet.

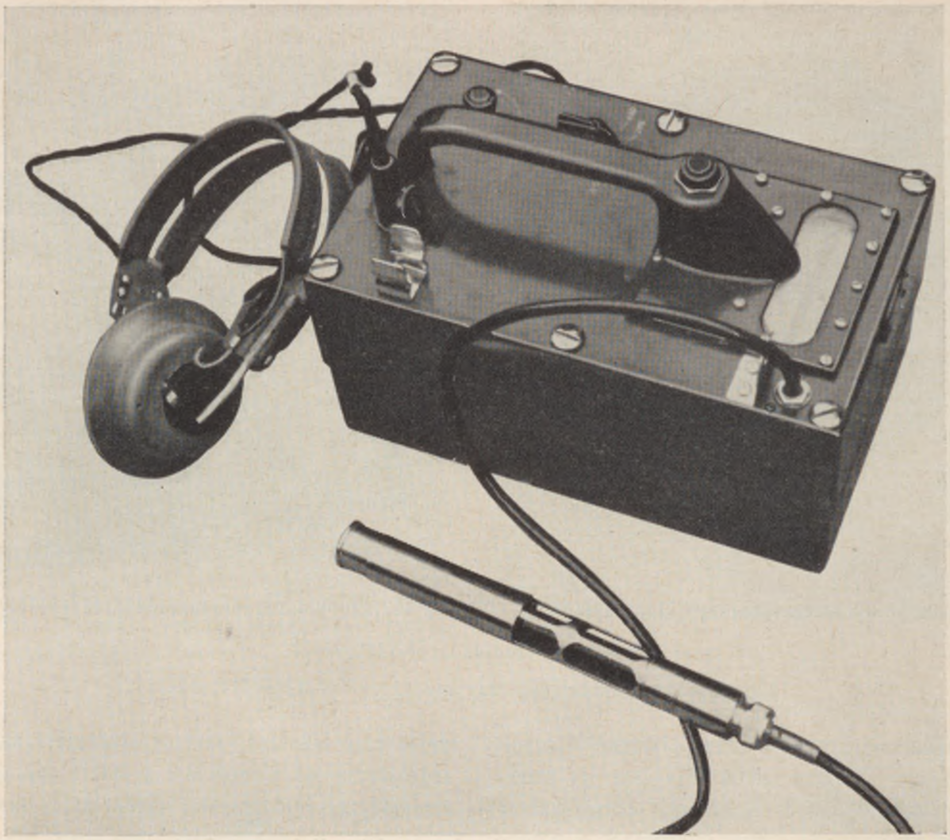


*Figure 74. The AN/PDR–T–2 Geiger-Mueller survey meter.*

A push-button for scale illumination is on the meter end of the handle. The shield on the tube probe is open, and the Geiger tube may be seen. Scale range—battery check switch and zero adjustment are partially obscured by the handle.

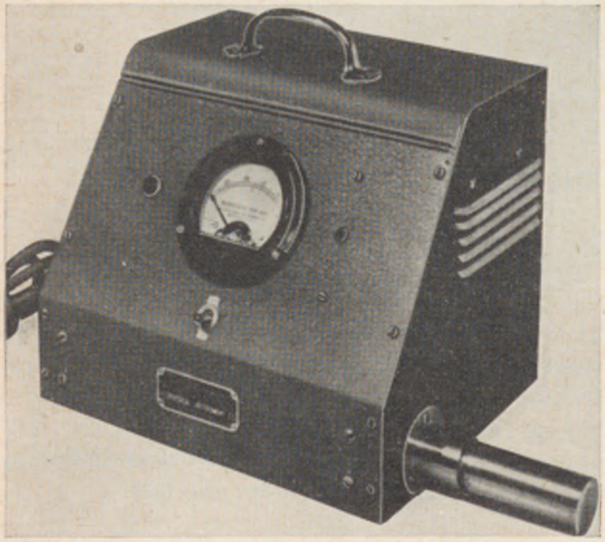


*Figure 75. Geophysical Instrument Company model 600 monitor.*

The Geiger tube case is shown at the lower right.

A hand and foot monitor, manufactured to military specifications, has reached an advanced state of development:

| | |
|---|---|
| Manufacturer | Radio Corporation of America. |
| JAN number | AN/UDR–10 (*f*). |
| Mfg. model number | EMA–2B. |
| AEC number | CGM–T4A. |
| Dimensions (inches) (approximate): | |
| Pedestal | 60 high, 48 wide, 30 deep (at base). |
| Control Unit | 42 high, 30 wide, 18 deep. |
| Weight (pounds) (approximate): | |
| Pedestal | 750. |
| Control cabinet | 250. |
| Power | 95–135 v, 60 cycle A. C. |

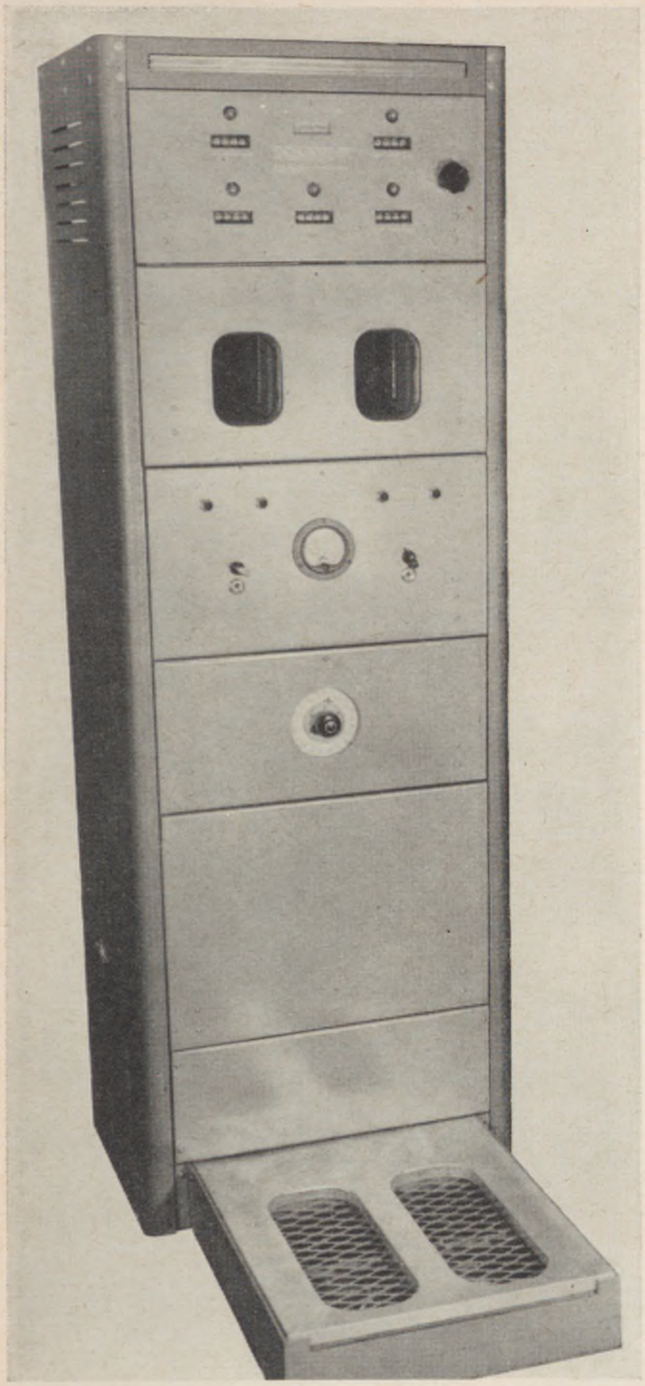


*Figure 76. Kelley-Koett model K–240 hand and foot counter (AN/UDR–3).*

The AN/UDR–10 is designed to operate automatically and indicate the degree of contamination of five selected areas as follows:

right hand—back
right hand—palm
left hand—back
left hand—palm
soles of both right and left shoes

Counts for each of the selected areas are separately channeled into five counting and recording systems. This unit has been designed for the convenience of both organization and personnel. Several pedestals may be placed in exit gates, etc., at any distance from the control cabinet which can be located; for example, in a guard house. Indication is by means of signal lights on both the pedestal and control cabinet.

### 15.07 Photomultiplier Survey Meters

| | | |
|---|---|---|
| JAN number | AN/PDR–11 (*f*) | AN/PDR–18 (*f*). |
| Radiation detected. | Alpha | Gamma. |
| Scale range | Up to 10,000 d/min. | 0.5, 5, 50, 500 r/hr. |
| Detector | Phosphor and photomultipliers in probe. | Phosphor and photomultiplier. |
| Indication | Output meter or headphone. | Output meter. |
| Weight (pounds) | 12 | 8½ (maximum). |
| Case dimensions (length x width x height in inches). | 6 x 3 x 12 | 6 x 4 x 10 (approx.). |

Both instruments are involved with later stage development and production engineering under direction of Bureau of Ships and should be ready for field test in 1950.

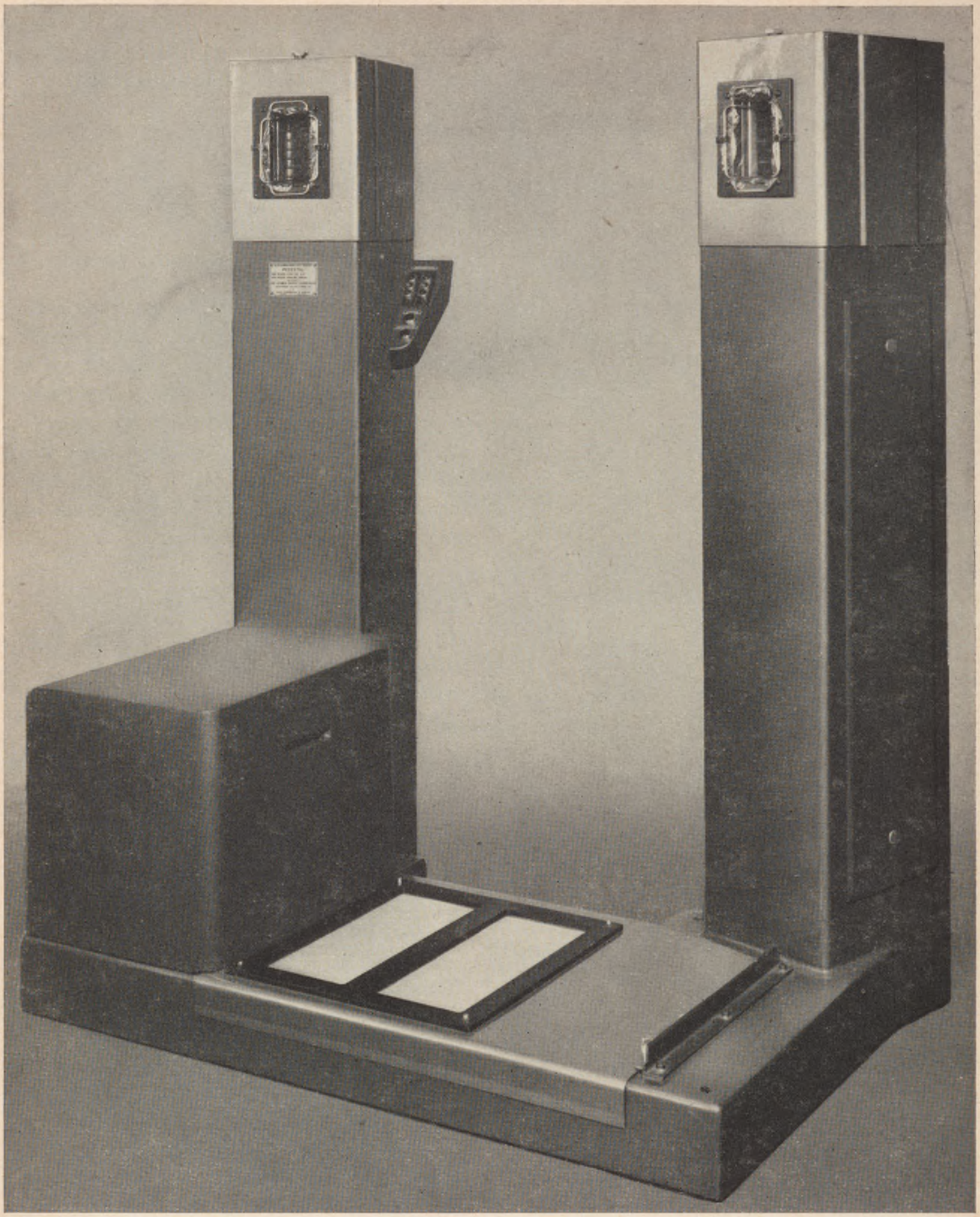


*Figure 77. AN/UDR–10 five-channel counter for detecting beta-gamma contamination of the hands and feet.*

Plastic envelopes in the hand holes may be changed after contamination. At the lower left is a box containing a roll of paper which replaces the paper covering the area used to monitor the soles of shoes.

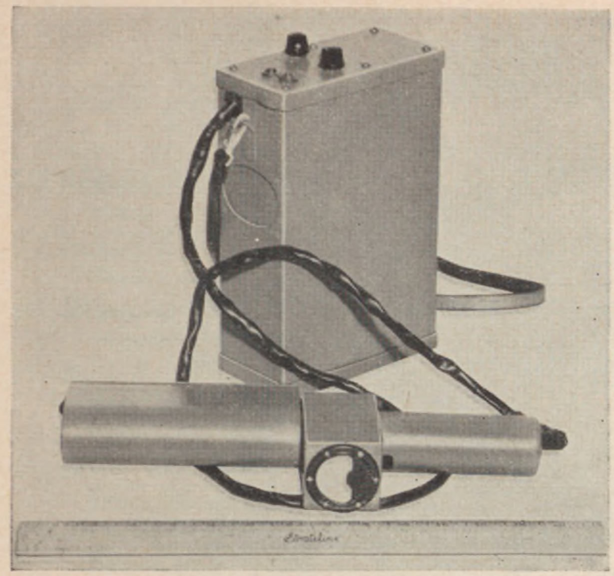


*Figure 78. AN/PDR-11(XN- ) alpha survey meter.*

The sensitive window is to the rear left of the probe in the picture foreground.

## 15.08 Film Badge

Dental film size packets, 1¼ x 1¾ inches not including waterproof coverings.

| Emulsion | Useful sensitivity range—Roentgens* Maximum density of 3 | Maximum density of 6 |
|---|---|---|
| Ansco non-screen | 0.03–2.0 | 7.5 |
| DuPont 502 | 0.03–3.0 | ------- |
| Eastman Type K | 0.05–1.0 | 10 |
| Ansco Super Ray | 0.2–3.0 | 20 |
| DuPont 552b | 0.5–10 | ------- |
| DuPont 552a | 4–20 | 50 |
| Eastman type A | 1.0–10 | 15 |
| Eastman Cine Pos. 5301 | 0.5–80 | 250 |
| DuPont 605 | 10–250 | 2,500 |
| Eastman Cine Pos. fine grain 5302. | 40–400 | 1,000 |
| Eastman Kodalith 6567 | 70–700 | ------- |
| Eastman Kodabromide G–3 | 470–8,000 | ------- |
| Eastman 548–0 double coat | 2,000–10,000 | ------- |
| Eastman 548–0 single coat | 5,000–20,000 | 50,000 |

*The sensitivity range of these film emulsions depends upon the choice of developer. Some nominal values are given which may be altered by as much as a factor of 100 through the use of different developing solutions. Densitometers (see page 35) having a top density reading of 3 have been in general photographic use for a number of years. The Weston Electrical Instrument Corporation manufactures such an instrument having a model number 6. The Ansco Division of the General Aniline and Film Corp. have recently marketed a Model 12 color densitometer which can measure a density of 6.

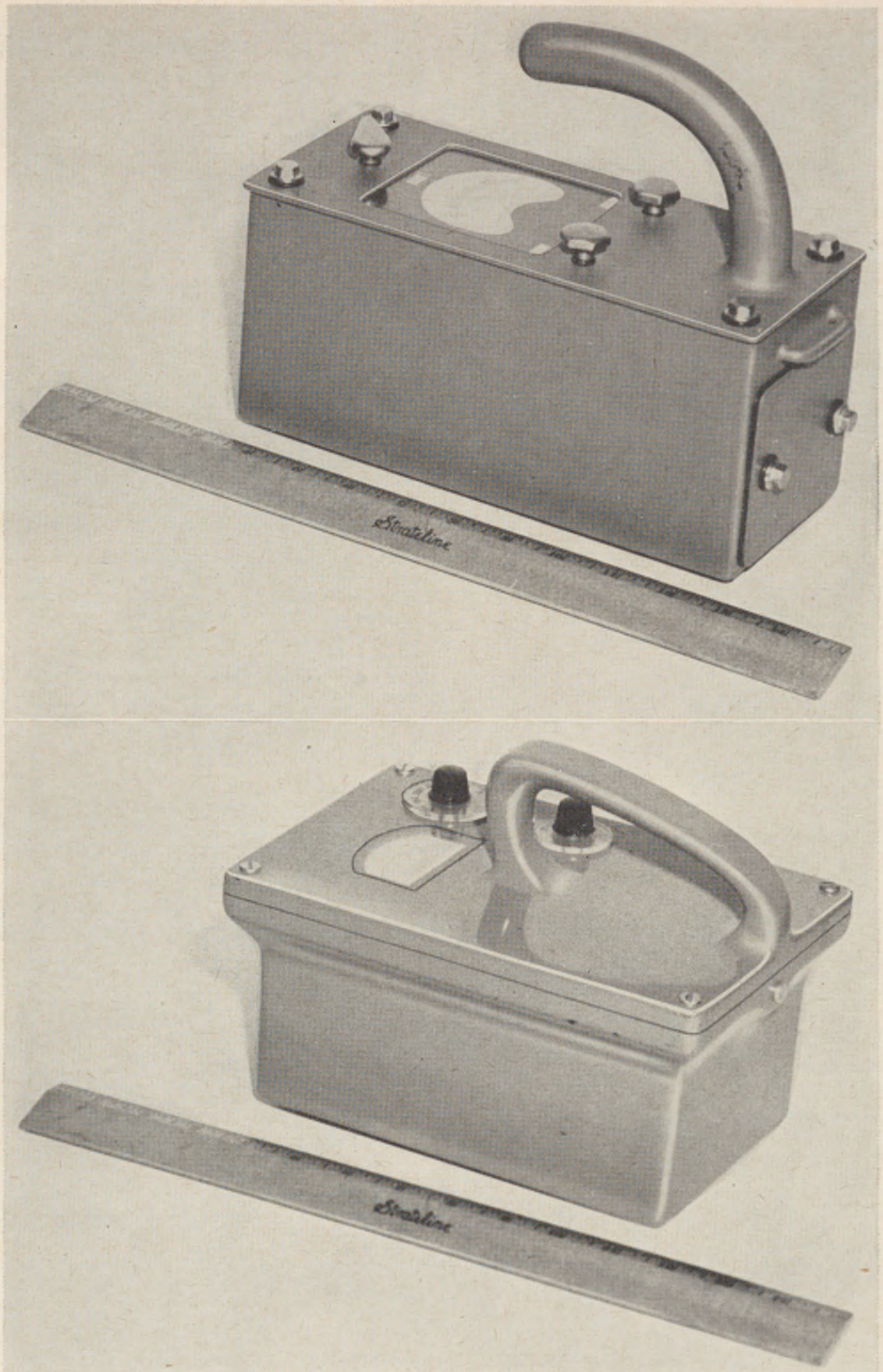


*Figure 79. AN/PDR–18 gamma photomultiplier survey meters.*

Two models are shown with experimental form factors. The final instruments may have no resemblance to those shown.

# REFERENCES*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(3) ***Strong, John.*** **Procedures in Experimental Physics.** Prentice-Hall, 1941.

(4) ***Rossi, B.*** and ***Staub, H. H.*** **Ionization Chambers and Counters: Experimental Techniques.** McGraw-Hill, 1949.

(5) ***Korff, S. A.*** **Electron and Nuclear Counters: Theory and Use.** D. Van Nostrand, 1946.

(6) ***Yagoda, H.*** **Radiation Measurements with Nuclear Emulsions.** Wiley, 1949.

(7) ***Pollard, Ernest and Davidson, W. L.*** **Applied Nuclear Physics.** Wiley, 1942.

(8) ***Andrews, H. L. and Campbell, D. C.*** **Evaluation of Radiological Survey Instruments used for Health Protection during Operation Sandstone.** Restricted. Sandstone Scientific Director's Report 31, Annex 10, 1 April 1949.

(9) **Radiological Defense,** Volume III. Armed Forces Special Weapons Project, 1949.

(10) **Radiation Instrument Catalog.** U. S. Atomic Energy Commission, Technical Information Branch, 1949.


*A more complete bibliography will be found in Nucleonics I, 68 (December 1947). Other bibliography and references which may be of interest to the reader can be found appended to Reference (9).

# Appendix I

## A-N NOMENCLATURE LIST

The following table lists A-N numbers for equipments now in field use or anticipated for use in the near future. It should be noted that this is far from a complete listing.

| Nomenclature | Instrument | AEC No. | Manufacturer | Model | Trade or code name |
|---|---|---|---|---|---|
| AN/ADR-1 | Airborne gamma dose rate. | | | | |
| AN/ADR-2 | Airborne dosimeter. | | | | |
| AN/PDR-2 | Ion chamber group dosimeter. | MIC-4A | Victoreen | 300 | Proteximeter |
| AN/PDR-3: | | | | | |
| IM-9/PD | Pocket dosimeter | PIC-7A | Kelley Koett | K-100 | |
| IM-9A/PD | Pocket dosimeter | | Kelley Koett | K-110 | |
| PP-311A/PD | Charger | AV-2D | Kelley Koett | K-135 | |
| PP-354B/PD | Charger | | Kelley Koett | | |
| AN/PDR-4: | | | | | |
| DT-16/PD | Pocket chamber | PIC-2C | Victoreen | 352 | |
| DT-16A/PD | Pocket chamber | PIC-1B | Nuclear Instrument and Chemical Co. | 3340 | |
| PP-316/PD | Charger-reader | AE-2A | Victoreen | 287 | Minometer. |
| AN/PDR-5: | | | | | |
| (IM-1A/PD) | Portable G-M detector | SGM-2B | Victoreen | 263A | |
| AN/PDR-7: | | | | | |
| (IM-8( )/PD) | Portable G-M detector | SGM-4B | Nuclear Instrument and Chemical Co. | 2610 | |
| AN/PDR-8 | Portable G-M detector | | Hoffman | | |
| AN/PDR-8A | Kidney shaped G-M | | Radio Corporation of America. | | |
| AN/PDR-8B | Portable G-M detector | | Hoffman | | |
| AN/PDR-8C | Portable G-M detector | | Admiral | | |
| AN/PDR-9 | Beta-gamma ion chamber. | SIC-4A | Argonne National Laboratory. | C2M10 | Betty Snoop. |
| AN/PDR-10 | Portable alpha proportional counter. | | General Electric | | Poppy. |
| AN/PDR-11 | Alpha scintillation counter. | | Radio Corp. of America | | |
| AN/PDR-15 | Portable G-M detector | | | | |
| AN/PDR-18 | Gamma scintillation counter. | | | | |
| AN/PDR-20 | Beta-gamma descriminating chamber. | | General Electric | | Zeus. |
| AN/PDR-21: | | | | | |
| DT-35( )/PD | Pocket chamber | PIC-2E | Kelley Koett | K-700 | |
| PP-43( )/PD | Charger-reader | AE-1B | Kelley Koett | K-425 | |
| AN/PDR-26 | Portable G-M detector | SGM-18A | El-Tronics | SM3 | |
| AN/PDR-27* | Portable G-M detector | | General Electric | | |
| AN/PDR-T-1 | Ion chamber survey | SIC-18A | Kelley Koett | K-350 | |
| AN/PDR-T-2 | Portable G-M detector | | El-Tronics | PR-2 | |
| AN/UDR-3 | Hand and foot monitor | CGM-17B | Kelley Koett | K-240 | |
| AN/UDR-10 | Hand and foot monitor | CGM-T4A | Radio Corp. of America | EMA-2B | |

*The AN/PDR-27 was once known as the AN/PPR-8E.

| Nomenclature | Instrument | AEC No. | Manufacturer | Model, name | Trade or code name |
|---|---|---|---|---|---|
| AN/USQ-1 | Gamma telemetenug | | | | |
| IM-3/PD | Ion chamber survey | SIC-9B | Victoreen | 247A | |
| IM-4/PD | Alpha-beta-gamma ion chamber. | SIC-2A | Victoreen | 356 | Zeuto. |
| IM-5/PD | Beta-gamma ion chamber | SIC-7A | Sylvania | RD-316 | Cutie pie. |
| | | SIC-7B | Tracer Lab | SU-1A | Cutie pie. |
| IM-7A/PD | Drift meter | SIC-5A | Kelley Koett | K-320 | |
| IM-39/PD | Portable G-M detector | SGM-15A | National Technical Laboratories. | MX-5 | |
| IM-40/PD | Ion chamber survey | SIC-15A | National Technical Laboratories. | MX-6 | |
| IM-50/PD | Pocket dosimeter | PIC-10A | A. O. Beckman Co | | |
| IM-51/PD | Pocket dosimeter | PIC-9A | Cambridge Instrument Co. | BM 17400 | |
| PP-354A/PD | Dosimeter charger | | Chatham Electronics | | |
| PP-527/PD | Dosimeter charger | AV-7A | Cambridge Instrument Co. | | |

# APPENDIX II

## GLOSSARY OF TERMS CONCERNED WITH RADIAC INSTRUMENTS

*Avalanche* ---- The action within proportional and Geiger counters in which one ion (electron) produces another ion by collision, these two ions (electrons) producing still further ionization.

*Background* --- The background count is that which is caused by any agency whatever other than the radiation which it is desired to detect. For health protection, it usually includes the radiations produced by naturally occurring radioactivity and cosmic rays.

*Calibration* --- The process of checking and adjusting instrument operation against known sources of radioactivity.

*Chamber* ----- A container in which ionization is allowed to take place and in which all the original ions are collected—otherwise known as an *ion chamber*.

*Count* -------- A terminated discharge produced by an ionizing event in a counter tube.

*Counter* ------ A device, such as a proportional counter or a Geiger-Mueller counter, which responds to or counts individual ionizing events.

*Count rate meter.* The instrument used to indicate the rate of counts indicated by a counting chamber or a proportional or Geiger counter. It may be used with both portable and laboratory equipment.

*Curie* -------- The curie is a standard measure of the rate of radioactive decay equal to $3.7 \times 10^{10}$ disintegrations per second.

*Dead time* ---- The time interval between individual counts in which a counter is insensitive.

*Densitometer* -- Electronic-Optical device used to determine the density (blackening) of film badges.

*Dosimeter* ----- An individual dosage indicating device—more specifically, a direct reading quartz fibre electroscope sensitive to gamma radiation and about the size of a fountain pen. Otherwise known as a pocket dosimeter, a pocket electroscope, or a quartz fibre dosimeter.

*Electrometer tube.* A specially constructed vacuum tube used for the amplification of minute currents such as those obtained from ionization chambers.

*Film badge* ---- A small packet containing photographic film which is used to obtain individual radiation dosage readings. Readings are primarily of gamma radiation.

*Geiger counter* - A low dose rate, high sensitivity detector of beta and gamma radiations. It may be either a light-weight portable detector or a laboratory instrument. Also known as a Geiger-Mueller counter.

*Geiger region* -- The part of the characteristic curve of pulse size as a function of voltage in which the size of the pulse is independent of the magnitude and type of radiation producing the initial ionizing event.

*Half life* ------ The time required for the disintegration of a radio-isotope to one-half of its initial rate of activity.

*Ionization* — The process by which a neutral atom or molecule loses an electron with the remaining ion becoming positively charged and the electron and positive ion forming an *ion pair*.

*Ionization chamber survey meter.* — A high dose rate, low sensitivity instrument for the measurement of gamma radiation—also known as a gamma survey meter or an ion chamber.

*Photographic dosimetry.* — The entire operation required to obtain individual dosage records by the use of film badges. This includes calibration, film development, densitometry, etc.

*Plateau* — The roughly horizontal part of the counting rate as a function of voltage curve in which there is very little change in count rate with change in voltage.

*Pocket chamber.* — A non-self-reading individual gamma dosage indicating device about the size of a fountain pen.

*Proportional counter.* — An instrument which counts alpha particles and descriminates against counts produced by beta and gamma radiations. It may be either a portable or a laboratory instrument.

*Proportional region.* — The portion of the characteristic curve of pulse size as a function of voltage in which the size of the pulse is proportional to the number of ions formed by the initial ionizing event.

*Quenching* — The process of extinguishing the action within a Geiger counter tube. External quenching utilizes an electronic circuit. A self-quench is produced by action within the counter tube.

*Recombination.* — The process of union between electrons and positive ions to form neutral atoms or molecules—the opposite of ionization.

*Recovery time* — The time interval after recording a count before the pulses produced by the next ionizing event in the counter are of substantially full size.

*Region of continous discharge.* — The part of the characteristic curve of pulse size as a function of voltage in voltages higher than those of the Geiger region. In this region the tube goes into a state of continuous discharge.

*Region of limited proportionability.* — The part of the characteristic curve of pulse size as a function of voltage in which the gas amplification depends both upon the numbers of ions produced in the initial event and upon the voltage (very little use).

*Roentgen* — For military purposes, this is a unit of dosage for the measurement of gamma radiation. This is the quantity of radiation which, under standard conditions, produces $2.08 \times 10^9$ ion pairs per cc of air.

*Scaler* — A laboratory electronic device used to record the number of pulses from a counter. An electronic circuit capable of dividing the incoming pulse rate by a constant factor so that mechanical methods of recording the pulse may be used.

*Threshold* — In the Geiger counter characteristic curve there are two thresholds: (a) The voltage below which no pulses are recorded is the characteristic curve threshold, and (b) the voltage at which the plateau starts is known as the threshold of the Geiger region.

# SUBJECT INDEX